Al - 8-
70

AN ELEMENTARY TEXT-BOOK OF ZOOLOGY

FOR INDIAN STUDENTS

Adapted from

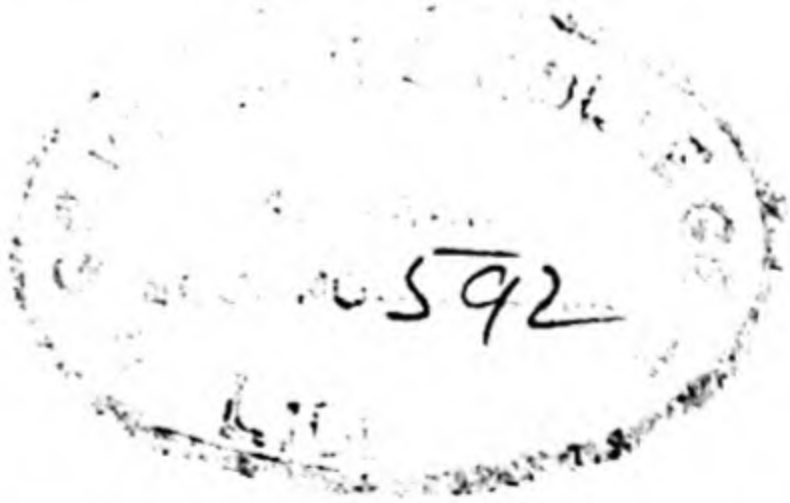
"AN ELEMENTARY COURSE OF PRACTICAL ZOOLOGY"
By Professors T. J. PARKER and W. N. PARKER

BY

B. L. BHATIA, D.Sc.

F.Z.S., F.R.M.S., F.A.Sc., F.N.I.
Kaisar-i-hind Medallist,
Principal, Ranbir College, Sangrur, formerly Assistant Professor of Zoology, Government College, Lahore, and later Principal, Government College, Hoshiarpur.

WITH ILLUSTRATIONS



MACMILLAN AND CO., LIMITED
ST. MARTIN'S STREET, LONDON
1949

Acc. No: 592

COPYRIGHT

First Edition 1921
Reprinted 1923
Second Edition 1928
Reprinted 1932, 1938
Third Edition 1940
Reprinted 1942, 1943, 1945, 1947, 1949

PRINTED IN GREAT BRITAIN

PREFACE

DURING recent years a considerable advance has taken place in the teaching of Zoology in Indian Colleges, and the want of a suitable text-book describing the Indian types has been keenly felt for some time. English text-books have had to be used so far, and the students had to be constantly warned as to the differences that might exist between the anatomy of the type actually used for study and the corresponding one described in such text-books. After a fairly long experience gained in teaching the subject, I made up my mind to do something to remove this long-felt want, so far as the Intermediate students in Indian colleges were concerned. Yet I felt that no useful purpose would be served in entirely re-writing the descriptions of several familiar animals, where the existing accounts could with comparatively slight modifications serve the purpose equally well. It was consequently decided to adapt the well-known "Elementary Course of Practical Zoology" by T. J. Parker and W. N. Parker for the purpose I had in view, and my obligations are due to the publishers and to Professor W. N. Parker for their ready acquiescence in my proposal.

I found myself in close agreement with the views of the original authors as regards the general plan of the book, and the following chief points on which they had originally agreed among themselves :—

"1. To adopt the method pursued in Huxley and Martin's 'Elementary Biology' of giving a connected

account of each example. 2. To give brief practical directions which should serve mainly as a guide, the student being able to refer, in case of difficulty, to the descriptive account preceding them. 3. In the larger animals, to arrange for as much work as possible to be done on one specimen: there is much to be said in favour of this plan apart from the fact that the average student cannot give sufficient time to the subject to dissect a fresh specimen for each system of organs. 4. To begin the course of instruction by an introductory study of one of the higher animals; to include in this introduction the elements of Histology and Physiology; and to select the Frog for the purpose: after trying various methods, I have found this plan to be the most satisfactory in practice. 5. To give drawings and diagrams of difficult dissections, and of details which the beginner cannot as a rule make out satisfactorily for himself. . . . 6. To include a short account of methods and technique limited to the barest essential outlines. . . ."

The following paragraphs might also be quoted from the preface to the original book, as indicating its general plan. "The time such students can devote to an elementary course in the subject is limited; and throughout the book I have borne in mind that the main object of teaching Zoology 'as a part of a liberal education is to familiarize the student not so much with the facts as with the ideas of the science,' but at the same time that he should be provided with a sound basis of facts so arranged, selected, and compared as to carry out this principle."

"Our original intention was to include one or more example of each of the larger phyla, and also to add a practical exercise after each type, giving general directions for the examination of an allied form for comparison. But I found that this would be impossible within the

space of a single volume, and it was therefore necessary to limit the descriptions mainly to those animals to which the students for whom the book is chiefly intended have to give special attention. This has resulted in rather a heavy balance on the side of Vertebrates; but, on the whole, I think that if sufficient work is done on the lower animals to illustrate certain main facts and generalizations, a comparative study of several vertebrates forms as good a training as any for beginners—more especially in the case of medical students."

The original being avowedly an elementary course of "Practical Zoology" is naturally based on the "type-system," the advantages and dangers of which are now well-known and fully recognized. In converting the book therefore into a more general text-book, an effort has been made to include after the description of each type a brief summary of the characters of the class to which the type belongs, and a number of other animals are also mentioned which the students would do well to examine. In Part I and Chapters I, II, IV, V, and IX of Part II such modifications have been made as were necessitated by the substitution of Indian types for those dealt with before. Chapters III, VI, VII, X of Part II àre written specially for this book. Chapter XI, dealing with Mammalia, has been revised and enlarged by the addition of a general elementary survey of the class. And finally two chapters dealing with the important subjects of Evolution, Variation, and Heredity have been added at the end. In these chapters an attempt has been made to introduce the student to some of the more important generalizations and conclusions so far arrived at in the domain of biological thought, only to an extent that would be justified on the basis of facts which he may be supposed to have gathered together. In its present form the book will

be found to cover fully the syllabuses for the Intermediate Examination in Science as laid down by the various Indian Universities.

In order to make the book more useful, about one hundred extra diagrams have been added, of which a certain number are new, and specially drawn for this book from actual specimens or dissections made by the author. Others have been modified or copied from the works of well-known authors, to whom due acknowledgment is made in every case.

I am deeply indebted to Professor J. Stephenson, D.Sc., C.I.E., University Professor of Zoology in the Punjab University, under whom the author has had the privilege of working for the last thirteen years, and to whose great learning and unrivalled experience as a teacher in this country the author himself owes so much, for his kindness in reading through a considerable part of the manuscript and suggesting many useful additions and alterations.

B. L. BHATIA.

GOVERNMENT COLLEGE, LAHORE,
November, 1919.

NOTE TO THIRD EDITION.

THE text has been thoroughly revised and brought up-to-date. Description of certain types and new matter has been added in order to cover the syllabuses for the Intermediate Examination of all the Indian Universities or Boards. In order to make room for new matter, practical directions formerly given at the end of each chapter, have been throughout omitted.

B. L. B.

CONTENTS

PAGE

PREFACE v

PART I

The Frog—An Introduction to Animal Life

CHAPTER I

SCOPE OF THE SCIENCE OF BIOLOGY—THE FROG : PRELIMINARY SKETCH OF ITS STRUCTURE, LIFE-HISTORY, AND VITAL FUNCTIONS 1

CHAPTER II

THE FROG (*continued*) : GENERAL INTERNAL STRUCTURE . 14

CHAPTER III

THE FROG (*continued*) : THE SKELETON 30

CHAPTER IV

THE FROG (*continued*) : THE JOINTS AND MUSCLES . . 52

CHAPTER V

THE FROG (*continued*) : WASTE AND REPAIR OF SUBSTANCE —THE DIGESTIVE ORGANS—NUTRITION 62

CHAPTER VI

THE FROG (*continued*) : THE VASCULAR SYSTEM—THE CIRCULATION OF THE BLOOD 74

CHAPTER VII

THE FROG (*continued*): THE MICROSCOPICAL EXAMINATION OF THE SIMPLE TISSUES . . . . . PAGE 97

CHAPTER VIII

THE FROG (*continued*): THE MICROSCOPICAL EXAMINATION OF THE COMPOUND TISSUES—GLANDS—SECRETION AND ABSORPTION 113

CHAPTER IX

THE FROG (*continued*): RESPIRATION AND EXCRETION . . 124

CHAPTER X

THE FROG (*continued*): THE NERVOUS SYSTEM 136

CHAPTER XI

THE FROG (*continued*): THE ORGANS OF SPECIAL SENSE . 161

CHAPTER XII

THE FROG (*continued*): REPRODUCTION AND DEVELOPMENT . 173

CHAPTER XIII

THE FROG (*continued*): MEANING OF THE TERM SPECIES—THE PRINCIPLES OF CLASSIFICATION—EVOLUTION—RECAPITULATION THEORY—GENERAL CHARACTERS AND CLASSIFICATION OF THE AMPHIBIA 190

PART II

Systematic Zoology

CHAPTER I

PHYLUM PROTOZOA

AMŒBA: CLASS SARCODINA 203

CHAPTER II

PHYLUM PROTOZOA (*continued*)

EUGLENA: VOLVOX: CLASS FLAGELLATA: DIFFERENCES BETWEEN ANIMALS AND PLANTS 214

CHAPTER III

PAGE

PHYLUM PROTOZOA (*continued*)

PARAMECIUM: PARASITIC CILIATES: VORTICELLA AND ITS ALLIES—COLONIAL ORGANISMS: CLASS CILIATA: BIOGENESIS AND ABIOGENESIS 227

CHAPTER IV

PHYLUM PROTOZOA (*continued*)

MALARIAL PARASITES—CLASS SPOROZOA—CLASSIFICATION OF THE PROTOZOA 248

CHAPTER V

PHYLUM CŒLENTERATA

HYDRA: OBELIA—SYMBIOSIS—ALTERNATION OF GENERATIONS—CHARACTERS OF THE PHYLUM CŒLENTERATA—CLASSIFICATION 260

CHAPTER VI

PHYLUM ANNELIDA

THE EARTHWORM: NEREIS—CHARACTERS OF THE PHYLUM ANNELIDA—CLASSIFICATION 292

CHAPTER VII

PHYLUM ARTHROPODA

CHARACTERS OF THE PHYLUM ARTHROPODA—THE PRAWN—THE COCKROACH—CLASSIFICATION 329

CHAPTER VIII

PHYLUM MOLLUSCA

THE FRESH-WATER MUSSEL—CHARACTERS OF THE PHYLUM MOLLUSCA—CLASSIFICATION 380

CHAPTER IX

BRIEF SURVEY OF THE OTHER PHYLA 397

CHAPTER X

SURVEY OF THE PHYLUM CHORDATA 406

CHAPTER XI

THE RABBIT AS A TYPE OF MAMMALIA—CHARACTERS OF THE CLASS—CLASSIFICATION 437

PART III

General Zoology

CHAPTER I

PAGE

THE CELL THEORY: CYTOPLASM: NUCLEUS: CELL-DIVISION: STRUCTURE OF THE OVUM: GAMETOGENESIS (SPERMATOGENESIS AND OOGENESIS): MATURATION AND FERTILIZATION OF THE OVUM: DIFFERENT TYPES OF OVA AND OF SEGMENTATION—EFFECT OF FOOD-YOLK ON DEVELOPMENT 525

CHAPTER II

DEVELOPMENT OF AMPHIOXUS: EARLY DEVELOPMENT OF OTHER TYPES, INCLUDING THE CHICK AND RABBIT: FORMATION OF THE CHIEF ORGANS OF VERTEBRATES, AND OF THE AMNION, ALLANTOIS, AND PLACENTA . . 545

CHAPTER III

EVOLUTION—EVIDENCES FOR EVOLUTION—THEORIES OF EVOLUTION 584

CHAPTER IV

SORTS OF VARIATIONS—CAUSES OF VARIATIONS—PHYSICAL BASIS OF HEREDITY—CONTINUITY OF THE GERM-PLASM—LAWS OF HEREDITY 621

INDEX 641

AN ELEMENTARY TEXT-BOOK OF ZOOLOGY

PART I

THE FROG—AN INTRODUCTION TO ANIMAL LIFE

CHAPTER I

SCOPE OF THE SCIENCE OF BIOLOGY—THE FROG: PRELIMINARY SKETCH OF ITS STRUCTURE, LIFE-HISTORY, AND VITAL FUNCTIONS

Biology, Zoology, and Botany.—Biology (Gk. *bios*, life, and *logos*, discourse) is the science which deals with all living things, under whatever aspect they may be studied. As the living objects are either animals or plants, Biology comprises the two sister sciences of Zoology (Gk. *zoon*, animal), which is the study of animals, and Botany (Gk. *botane*, plant), which deals with plants. Each of these has several divisions. Morphology (Gk. *morphe*, form) deals with the form and structure, and Physiology (Gk. *phusis*, nature) with the functions of the organisms concerned. Thus under Zoology we will be studying animal morphology and animal physiology. Morphology includes the study of the grosser structure of the organism

as seen by the naked eye, which goes by the name of Anatomy (Gk. *ana*, up; *tome*, cutting), and the study of the structure as revealed by the aid of the microscope, which is known as Histology (Gk. *histos*, tissue). Thus Botany and Zoology deal with the study of the structure, the mutual relations, and the arrangement or classification of plants and animals. But biology may also be pursued, and very profitably pursued too, quite independently of teachers, classrooms, and examinations. The country boy who knows the song of every bird, its nesting-place, the number of its eggs, the nature of its food, the lurking-place of the trout in the stream or the frogs in the marsh; who has watched the ants with their burden of grain, or the bees with their loads of honey or pollen; has begun the study of biology in one of its most important branches. The intelligent gardener who observes the habits of plants, their individual tastes as to the soil, moisture, sunshine, and the like, is also something of a biologist without knowing it. So also is the collector of eggs, shells, or insects, provided he honestly tries to learn all he can about the objects he collects, and does not consider them merely as a hoard or as objects for barter. Indeed, all that is often spoken of as natural history, so far as it deals with living things—plants and animals—and not with lifeless natural objects, such as rocks and minerals, is included under the head of biology.

What then is the connection between biology in this wide sense and the kind of thing you are expected to learn in a limited number of lessons? Simply this:—In the classroom Nature cannot be studied under her broader aspects: indeed, much out-door natural history cannot be *taught* at all, but must be picked up by those who have a love of the subject, a keen eye and patience. But there is one thing we can do within the narrow

limits of the classroom: we can confine ourselves to some department of biology small enough to be manageable: we can take, for instance, one or more familiar animals and plants and, by studying them in some detail, get some kind of conception of animals and plants as a whole. This book deals with the zoological side of biology only; and what we have now to do is, in fact, what you have often done in the study of English: you take a single verse of a poem at a time, analyse it, parse it, criticise its construction, try to get at its exact meaning. If you have any real love of literature this detailed study of the part will not blind you to the beauty of the whole. And so if you have any real love of Nature, the somewhat dry and detailed study we have now to enter upon should serve to awaken your interests in the broader aspects of biology by showing you, in a few instances, what wonderful and complex things animals are.

One word of warning before we begin work. You must at the outset disabuse your mind of the fatal error that zoology or any other branch of natural science can be learnt from books alone. In the study of languages the subject-matter is furnished by the words, phrases, and sentences of the language; in mathematics, by the figures or other symbols. All these are found in books, and, as languages and mathematics are commonly the chief subjects studied at school, they tend to produce the habit of looking upon books as authorities to which a final appeal may be made in disputed questions. But in natural science the subject-matter is furnished by the facts and phenomena of nature; and the chief educational benefit of the study of science is that it sends the student direct to Nature, and teaches him that a statement is to be tested, not by an appeal to the authority of a teacher or of a book, but by careful and repeated observation and experiment.

The object of this book, therefore, is not only to give you some idea of what animals are, but also to induce you to verify for yourself the statements contained in it. The description of each animal you should follow with the animal before you; and if you find the account in the book does not agree with what you see, you must conclude, not that there is something wrong with your subject, but either that the description is imperfect or erroneous, or that your observation is at fault and that the matter must be looked into again. In a word, zoology must be learnt by the personal examination of animals: a text-book is merely a guide-post, and all doubtful points must be decided by an appeal to the facts of nature.

It matters very little what animal we choose as a starting-point—a rabbit, a pigeon, or an earthworm—one will serve almost as well as another to bring out the essential nature of an animal, how it grows, how it is nourished, how it multiplies. On the whole, one of the best subjects to begin with is a frog: partly because it is easily obtained, partly because its examination presents no difficulties which an intelligent student may not be expected to surmount by due exercise of patience.

Let us therefore begin our studies by catching a **frog** and placing it in a convenient position for examination, as, for instance, under an inverted glass bell-jar or even a large tumbler.

External Characters.—Notice, first of all, the short, broad *trunk*, passing insensibly in front into the flattened *head*—there being no trace of a neck—and ending behind without the least vestige of a tail: these constitute the *axial* parts of the animal. In the ordinary squatting position the back has a bend near the middle, producing a peculiar humped appearance. The head ends in front

in a nearly semicircular *snout*, round the whole edge of which extends the huge slit-like *mouth*. On the top of fore-end of the snout are the two small *nostrils*, one on each side of the middle line; and some distance behind them, the large, bright, prominent *eyes*, in which we can

FIG. 1.—*Rana tigrina*, the common Indian Frog. (After Boulenger.)
Reproduced by permission from "Fauna of British India."

distinguish, as in our own eyes, a coloured ring or *iris*, surrounding a roundish black space or *pupil*. The *eyelids*, however, are rather different from our own: the upper is fairly well developed, but the lower is a mere fold of skin, incapable itself of covering the eye, but produced into a thin transparent skin, the *nictitating membrane*,

which can be drawn upwards over the eye. The entire absence of eyebrows and eyelashes is a point worthy of notice.

Extending backwards from the eye is a large dark patch, in the middle part of which is a circular area of tightly stretched skin, reminding one of the parchment of a tambourine; this is the *drum-membrane* or *tympanic membrane*, a part of the ear. Here again we see a striking difference from our own organs: in ourselves the drum-membrane, instead of being flush with the surface of the head, is placed at the inner end of a deep passage or tunnel, the entrance to which is guarded by the large external ear. Of the latter there is no trace in the frog.

Attached to the trunk are two pairs of offshoots or *appendages*, the arms and legs, or *fore-* and *hind-limbs*, in which the resemblance to our own limbs will be at once obvious. The arms are very short: each consists of an *upper-arm*, a *fore-arm*, and a *hand*, the latter provided with four *fingers*, which are slender and tapering and have no nails. The legs, on the other hand, are very long: each consists of a stout *thigh*, a long *shank*, with a well-marked "calf," and a very curious *foot*. The *ankle-region* is long—almost like a second shank—and has no heel: it is followed by five *toes*, the first or innermost short, the second of moderate length, the third longer, the fourth longer still, and the fifth of about the same length as the third. All the toes are joined together by thin transparent *webs*, and, like the fingers, have no nails. Length of foot is characteristic of many other animals capable of powerful leaping, *e.g.*, kangaroos, rabbits, etc. The adult frog hops about on land, the long and powerful hind-limbs enabling it to jump, the smaller fore-limbs being used to break the fall, when it alights on the ground. Occasionally the frog goes into

the water, where the powerful hind-limbs and the webbed toes enable it to swim. The name *digit* is conveniently applied both to fingers and toes. Between the bases of the thighs, at the hinder end of the trunk, is a small aperture, the *vent* or *cloacal aperture*.

In the squatting posture the body is raised upon the arms, which are kept slightly bent at the elbows, with the fingers spread out and directed forwards. In this position the innermost of the four fingers corresponds with our own index-finger, the frog having no thumb. The hind-limb, in similar circumstances, is bent into a sort of Z, the knee being directed forwards and the ankle-joint backwards. The toes are turned forwards, and the inner one, which is the smallest of all, corresponds with our own great toe.

Owing to the bent position of the limbs, we cannot very well, as in our own arms and legs, speak of their upper and lower ends. It is therefore customary to call the end of a limb, or of any division of a limb, which is nearest to the trunk, the *proximal* end, that which is farthest away the *distal* end. Thus the proximal end of the fore-arm is the elbow region, the distal end of a digit is its tip.

In the largest Indian Frog (*Rana tigrina*), which is common all over India and Ceylon, the whole body, including head, trunk, and limbs, is covered with a soft, slimy skin of a green or olive colour, irregularly mottled with dark spots of varying size on the upper or *dorsal* surface, and whitish on the under or *ventral* surface. The colouring is, however, not constant; in a frog kept in the dark the black spots increase to such an extent that the whole animal becomes almost black, while if kept in full daylight a corresponding brightening of the tints takes place. Moreover, the spots and patches of brighter colour are very variable: if you examine a

dozen specimens you will see at once that no two are alike in this respect. The skin on the dorsal surface shows longitudinal folds with a strong fold above the tympanum.

Sexual Characters.—As in so many of the more familiar animals, there are two sexes of frogs, easily distinguished from one another. If you examine several of them you will find that a certain number have on the palm of the hand, towards the inner side, a large swelling, rather like the ball of our own thumb, but much more prominent and of a black colour, especially at the breeding season. Frogs having this structure are males; it is not present in the females. Moreover, the males among the common Indian type (*Rana tigrina*) are usually of a darker colour than the females, and on the ventral surface of the head possess loose folds of skin, one on each side of the throat, a little behind the articulation of the jaws. These allow the expansion of the underlying vocal sacs, which help to intensify the noise produced by the frog, familiarly known as the croak.

Actions Performed by the Living Frog.—Kept under suitable conditions a frog shows *evidences of life*. If touched or otherwise alarmed it attempts to escape by making a series of vigorous leaps—suddenly extending the hind legs and jumping to a considerable height. Thrown into water it swims by powerful strokes of the hind-limbs. It has thus, like so many living things with which we are familiar, the power of *voluntary movement*.

If a young frog is kept under observation for a sufficient time—weeks or months—it will be found that it *grows* until it reaches a certain limit of size. Growth, in the case of the frog, is an increase in size and weight affecting all parts of the body, so that the proportions remain practically unaltered, and no new parts are added.

Careful observation shows that the throat is constantly

rising and falling, and the nostrils opening and shutting. These movements, like the expansion and contraction of the human chest, are *respiratory* or breathing movements, and serve to pump air into and out of the lungs.

It requires frequent watching and sharp observation to see a frog *feed*. It lives upon insects, worms, slugs, and the like. Opening its mouth it suddenly darts out a tolerably long, nearly colourless, and very sticky *tongue*; if the prey is a small insect, such as a fly, it adheres to the end, and the tongue is quickly drawn back into the mouth, the whole operation being performed with almost inconceivable rapidity.

Like other animals the frog discharges *waste matters* from its body. Its droppings or *fæces*, discharged from the vent, are black and semi-solid. From the same aperture it expels periodically a quantity of *urine*, which is a perfectly clear and colourless fluid, and contains water with a minute quantity of certain substances dissolved in it.

Sometimes a frog will escape from confinement, leaving its damp box or vivarium for the warm, dry atmosphere of an ordinary room. When this happens the animal is usually found next morning dead and shrunken, and with its naturally moist skin dry and hard. From this it may be inferred that there is a constant *evaporation of water* from the skin, which, in ordinary circumstances, is checked by a damp atmosphere or by occasional immersion in water.

Hibernation.—In winter frogs bury themselves in damp places, and become sluggish, manifestations of life becoming hardly apparent until the following spring, when they emerge from their holes. In this way they escape the dangers of frost which would otherwise be fatal to them. This suspension of activity during winter is known as *hibernation*, or the winter-sleep.

Reproduction and Development.—If you examine a number of frogs in summer, you will find that the full-grown females are distinguished from the males, not only by the absence of the pad on the hand, but also by the swollen condition of the trunk, due to the interior being distended with *eggs*. In the rainy season, the frogs go into water for sexual union. The male frog clasps the female, and the swelling covered with rough skin on the ventral surface of its hand prevents the female from slipping. The female passes out of its vent a mass of eggs. Each egg is a little globular body about $\frac{1}{12}$th inch in diameter, half black and half white, and surrounded by a sphere of clear jelly, by means of which the eggs adhere together in large irregular masses, the well-known "frog-spawn." As the eggs are laid, the male passes out of his body, also by the vent, a milky *spermatic fluid*, which gets access to the eggs and *impregnates* or *fertilises* them. Without impregnation they are incapable of developing.

Neither male nor female takes the slightest care of the eggs when once they are deposited and fertilised. They are simply left in the water unprotected in any way; and, naturally enough, the mortality among them during the course of development is very great, the majority being eaten or otherwise destroyed, and only a very small percentage coming to maturity.

The first noticeable change in the spawn is that the sphere of jelly surrounding each egg swells up so as to acquire several times the diameter of the enclosed egg. The egg itself, or *embryo*, as it must now be called, gradually becomes entirely black, then elongates, and takes on the form of a little creature (Fig. 2, 1) with a large head, a short tail, and no limbs; which, after wriggling about for a time, escapes from the jelly and fixes itself, by means of a sucker on the underside of its head,

to a water-weed. Great numbers of these *tadpoles*, as the free-living immature young or *larvæ* of the frog are called, may be seen attached in this way. At first they

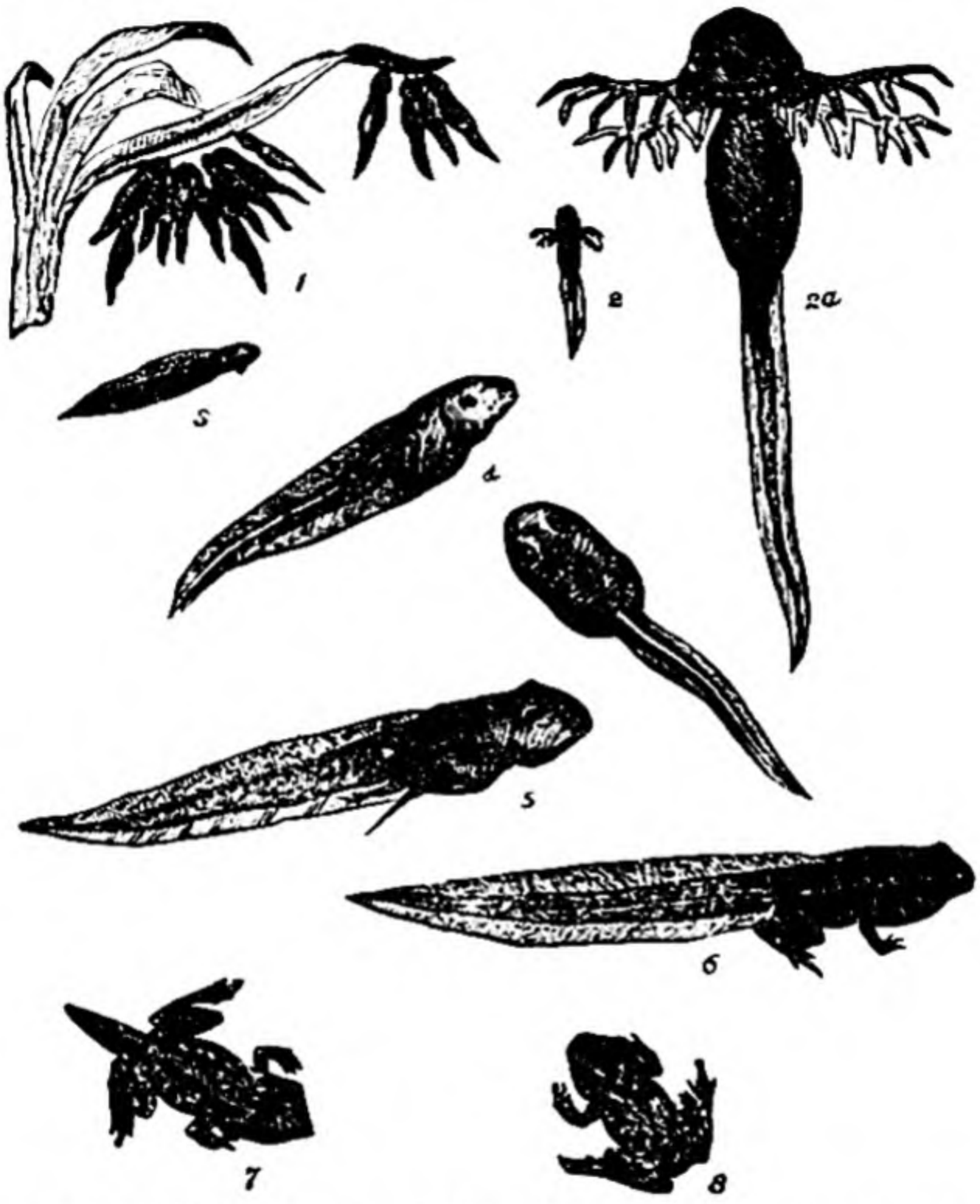


FIG. 2.—Stages in the life-history of a Frog, from the newly-hatched tadpoles (1) to the young frog (8). Natural size.—2a is a magnified view of 2. (After Mivart.)

are sluggish and do not feed, but, before long, they begin to swim actively by lashing movements of their tails, and to browse on the weeds. They are thus in the main vegetable-feeders, not carnivorous, like the adult frog. On each side of the head appear at first two, later three,

little branched tufts or *gills*, which serve as respiratory organs (2, 2ª), the tadpole, like a fish, breathing air which is dissolved in the water. After a while the gills begin to shrivel up (3, 4), and the tadpole then comes periodically to the surface to breathe, lungs having in the meantime made their appearance. A pair of little hind-limbs appears at the root of the tail, and a pair of fore-limbs behind the head (5, 6). As these increase in size the tail slowly dwindles, the head and trunk assume the characteristic frog-form, and the animal now comes on land and hops about as a small tailed frog (7). As growth goes on, the tail further diminishes and finally disappears altogether, the transformation or *metamorphosis* being thus completed (8).

The study of the frog in the living condition thus acquaints us with the general characteristics of all animal life. All animals feed and grow, breathe and excrete waste matter, show voluntary movement, irritability or response to outside stimuli, and sooner or later reproduce their kind. The substances taken as food are digested, absorbed and ultimately assimilated, becoming part and parcel of the body and causing its growth. This sequel of changes or building up of the body is described as *anabolism*. At the same time the substance composing all parts of the body is undergoing various processes of breaking down or *katabolism*. The sum total of all the chemical changes going on in the living body is described as *metabolism*.

Death and Decomposition.—Frogs may live for many years, but, sooner or later, either in the ordinary course of nature or by accident, they die. The heart stops beating, the flesh undergoes what is called " death-stiffening," becoming hard and rigid, and all vital manifestations cease. Before long the process of decomposition ensues, the flesh, viscera, etc., soften and emit a bad smell, and

in course of time rot away completely, leaving only the bones.

Summary of Chapter.—The very brief and cursory study we have made so far shows us (1) that a frog has certain definite *parts* arranged in a particular way; (2) that it performs characteristic *movements*, some of them, such as leaping and swimming, voluntary; others, such as *breathing*, involuntary; (3) that it takes in *solid food*, consisting mainly of vegetable matter in the tadpole, of living animals in the adult, and grows; (4) that it gives off *waste matters*; (5) that it *reproduces* its kind by laying eggs, which develop only if impregnated; (6) that it undergoes transformation or *metamorphosis*, the egg giving rise to a *larva*, the tadpole, which, after living for a time the life of a fish, gradually changes into a frog.

CHAPTER II

THE FROG (*continued*): GENERAL INTERNAL STRUCTURE

You have now seen that a frog can perform a number of very complicated actions; and, if you have any curiosity in these matters, you will probably want to know something of the mechanism by which these actions are brought about. Now, the best way to understand the construction of a machine, such as a clock or a steam-engine, is to begin by taking it to pieces; and, in the same way, you can find out the parts of which the living machine we call a frog is made, and the way they are related to one another, only by taking it to pieces, or *dissecting* it.

First notice, in addition to the external characters described in the last chapter, that the various parts of the body are strengthened or stiffened, as in ourselves, by a number of *bones*, which together form the greater part of the *skeleton*. It is quite easy to ascertain by feeling that the head contains a hard *skull*; the lower jaw, a lower-jaw-bone, or *mandible*; that running through the back is a jointed backbone or *vertebral column*; that the region of the chest is protected by a breastbone or *sternum*; and that each division of the limbs has its own bone or bones.

The Mouth-cavity.—There are also several points to be observed in the interior of the mouth. All round the edge of the upper jaw is a row of small conical *teeth*

(Fig. 8). There are no teeth in the lower jaw; but on the roof of the mouth, a short distance behind the snout, are two little patches of teeth, called the *vomerine teeth* (*vo. t*), and nearer the jaw are two apertures, called the *internal nostrils* (*p. na*): a guarded bristle passed into one of the external nostrils and pushed gently backwards and downwards will be found to enter the mouth by the corresponding internal nostril.

Behind the internal nostrils are two large hemispherical projections, due to the roof of the mouth being bulged out by the huge eyes, as can be readily made out by pushing the eyes from outside.

On the floor of the mouth is the large, flat *tongue* (*tng*), remarkable for the fact that it is attached at its front end, its hinder end being free and double-pointed. When the frog uses it to catch insects it is suddenly thrown forwards, almost like a released spring. The surface of the tongue being sticky, the prey is held fast and devoured as a whole, by the tongue being withdrawn, as quickly, back into the mouth-cavity. Just behind the backwardly-turned tips of the tongue is an oval elevation, having on its surface a longitudinal slit, called the *glottis* (*gl*), which leads, as we shall see afterwards, into the lungs.

The back of the mouth narrows considerably, and the soft skin or *mucous membrane* lining it is here thrown into folds. A probe gently pushed backwards passes, as we shall see, into the stomach. The narrowed region of the mouth is the throat, or *pharynx*. On its upper wall, near the angles of the mouth, are two openings leading into tubular passages: a guarded bristle passed into one of these will be found to come into contact with the corresponding tympanic membrane, which will be pierced if sufficient force is used. The tubes are known as the *Eustachian tubes* (*eus. t*).

Dissection of the Frog: Skin and Muscles.—If a slit is made in the skin of the belly, and a probe pushed in under it, it will be seen that the skin, instead of being firmly attached to the underlying flesh, as in a rabbit or a sheep, is for the most part quite loose, a spacious cavity lying between it and the flesh. Not, however, a single continuous cavity for the whole body: the probe, gently pushed in various directions, is stopped, in front, at about the level of the arms; behind, at the junction of the thighs with the trunk; and at each side, along an oblique line joining the armpit with the thigh. Moreover, by opening the skin of the back, throat, and limbs, and inserting the probe as before, similar cavities will be found in these regions, all separated from one another by partitions, along which the skin is firmly united to the underlying flesh. It will be noticed also that the probe, when withdrawn from any of these cavities, is wet. The cavities contain a watery fluid, called *lymph*, and are hence known as *subcutaneous lymph-sinuses* (Fig. 8, *d. ly. s*, *v. ly. s*).

When the skin is removed it will be seen that under the skin and separated from it by the lymph-sinuses is a nearly colourless, semi-transparent, fibrous substance, the flesh. At first this appears to be continuous over the whole body, but, by careful dissection with a sharp scalpel, a very delicate, transparent skin, called the *fascia*, can be separated from the flesh, which is then seen to consist of a number of separate bands (Fig. 3, *my. hy*, *pct*, *rct. abd*; see also Fig. 19), covered as aforesaid by the fascia, and separated from one another by a kind of packing substance, also very delicate and transparent and known as *connective-tissue*. These bands or sheets are the *muscles*, and the whole of the flesh is made up of distinct muscles, readily separated from one another when once the requisite anatomical skill is attained.

Here and there—for instance on the top of the head and the front of the shanks—there are no muscles, and the bones are covered only by skin and connective-tissue.

Passing along the middle line of the belly is a dark

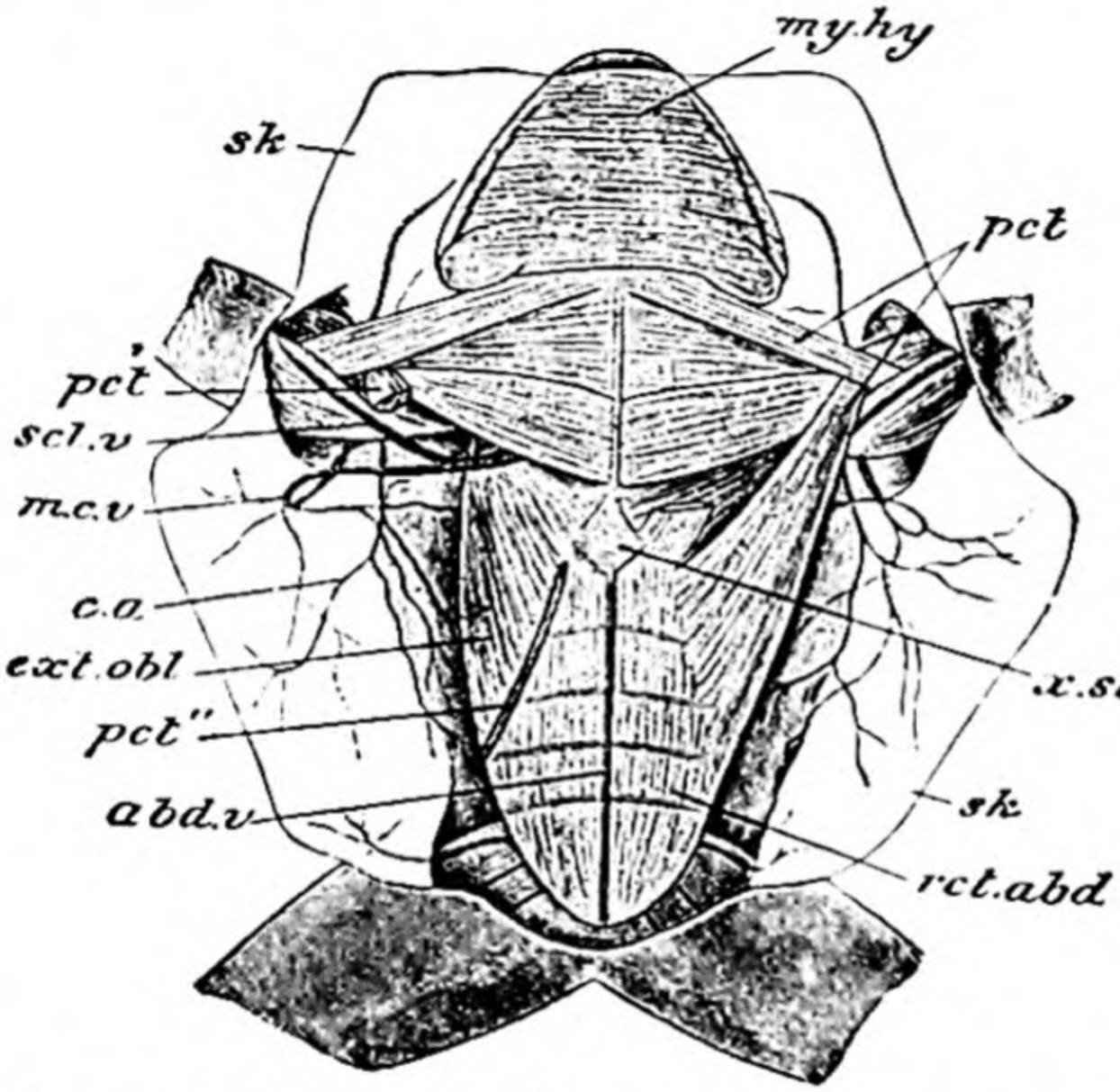


FIG. 3.—A Frog with the skin (*sk*) of the ventral surface cut through and turned back right and left, so as to expose the muscles. Of these the mylohyoid (*my. hy*), pectoralis (*pct*), external oblique (*ext. obl*), and rectus abdominis (*rct. abd*) are lettered. On the right side (left in the figure), the posterior portion of the pectoral muscle is cut away, its two ends (*pct'*, *pct''*) only being left. The cartilaginous extremity of the breast-bone (xiphisternum, *x. st*) is shown, as well as the abdominal (*abd. v*), musculo-cutaneous (*m. c. v*), and brachial (*scl. v*) veins, and the cutaneous artery (*c. a*). (Natural size.)

longitudinal streak (Fig. 3, *abd. v*) : this is a *blood-vessel*, the *abdominal vein*. On each side of the body another vein (*m. c. v*) is seen forming a loop, one limb of which is on the turned-back flap of skin, while the other passes between the muscles not far from the armpit : this vessel

is the *musculo-cutaneous vein*. Both these veins, and many others which will be seen in the course of the dissection, are thin-walled tubes full of *blood*, as will be proved if you should happen to cut one of them, when the blood will escape in considerable quantity.

Between the right and the left fore-limbs the ventral region of the trunk is protected by certain bones which form part of the *shoulder-girdle*: projecting backwards from this in the middle line is a flat, bi-lobed plate of a softer substance, known as *cartilage* (compare Fig. 14). Immediately between the thighs a cartilage called the *pubis*, part of the *hip-girdle* (Fig. 17), can be felt. Between the shoulder- and hip-girdles the ventral body-wall is soft, being formed only of muscle and connective-tissue.

The Body-cavity and its Contents.—By cutting through the muscles of the belly or *abdomen*, a large cavity, the *body-cavity* or *cœlome*, is exposed, in which are contained numerous structures presently to be described. In order, however, to open the whole of the cavity the ventral part of the shoulder-girdle must be removed.

In the middle line, between the fore-limbs, and therefore covered in the entire animal by the shoulder-girdle, is a pink conical body (Figs. 4 and 5, *v*) connected in front with a thin-walled bag (*r. au*, *l. au*), of a purplish colour. The whole thing is the *heart*: the pink posterior portion is called the *ventricle*: the purple anterior part consists of two chambers, the *auricles*. The heart is enclosed in a transparent, membranous bag, the *pericardium*, which contains a lymphatic fluid.

Just behind or posterior to the heart are two large masses (*lr*) which have a dark reddish-brown colour; these are the right and left lobes of the *liver*. They extend forwards, one on either side of the heart: between them is a globular bag of a greenish colour (Fig. 4, *gl. bl*),

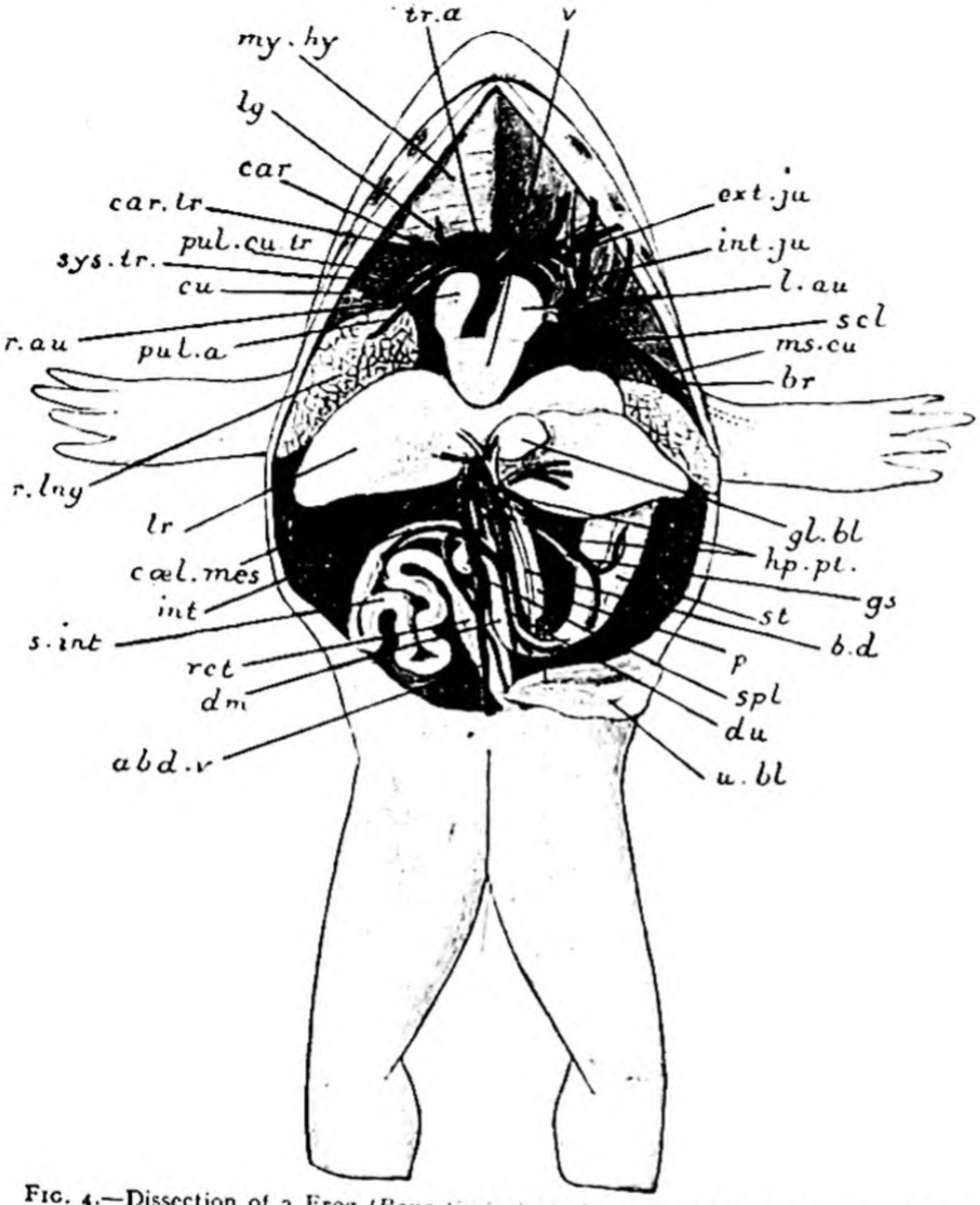


FIG. 4.—Dissection of a Frog (*Rana tigrina*) to show the chief viscera exposed on opening the body-cavity, along with some of the principal arterial and venous trunks. Right precaval vein and its branches are not shown. Arteries are coloured red, veins are coloured blue. (Natural size.) (B.L.B.)

abd. v. abdominal vein; *br.* brachial vein; *b. d.* common bile and pancreatic duct; *car.* carotid artery; *car. tr.* carotid trunk; *cæl. mes.* cœliaco-mesenteric artery; *cu.* cutaneous artery; *dm.* duodenum; *du.* duodenal artery and vein; *ext. ju.* external jugular vein; *gl. bl.* gall bladder; *gs.* gastric artery; *hp. pt.* hepatic portal vein; *int.* intestinal artery and vein; *int. ju* internal jugular vein; *l. au.* left auricle; *lg.* lingual artery; *lr.* liver; *ms. cu* musculo-cutaneous vein; *my. hy.* mylo-hyoid muscle; *p.* pancreas; *pul. a.* pulmonary artery; *pul. cu. tr.* pulmo-cutaneous trunk; *r. au.* right auricle; *rct.* rectum; *r. lng.* right lung; *scl.* subclavian vein; *s. int.* ileum; *spl.* spleen; *st.* stomach; *sys. tr.* systematic trunk; *tr. a.* truncus arteriosus; *u. bl.* urinary bladder; *v.* ventricle.

the *gall-bladder*. In front of the liver and left and right of the heart are two thin-walled transparent sacs (*r. lng*, *l. lng*) with a honeycombed surface, the *lungs*. Their appearance varies very much according to their state of distension. When full of air they are about 2 inches in length in a full-sized frog, and protrude freely as soon as the body-cavity is opened: when empty they hardly show unless the liver is turned aside.

Emerging from beneath the left lobe of the liver (*beneath* in the present position of the animal, actually *above*) is a wide whitish tube (Fig. 4, *st*), which almost immediately turns to the right (the frog's right, not yours), so as to form a **U**-shaped bend (*st*, *dm*). This is the *stomach*, which is connected with the pharynx by a short tube called the *gullet* or *œsophagus* (compare Fig. 8, *gul*, *st*), and which varies considerably in size according to whether it is empty or distended with food. The stomach becomes continuous with a narrower tube, the first part of which (*dm*) passes forwards parallel with the stomach, thus forming the narrow limb of the **U**, while the rest of it (*s. int*) is thrown into a rather complex coil. This tube is the *small intestine*; the part in immediate connection with the stomach (*dm*) is distinguished as the *duodenum*, and the coiled part as the *ileum*. Between the stomach and the duodenum, in the bend of the **U**, is a small yellowish-white body of irregular form, the *pancreas* (Figs. 8, *pn*, and 4, *p*). Very often the specimens of *Rana tigrina* are found to be infested with a large numb of parasites belonging to a group known as the hook-worms. These are small, white, oval bodies, often forming a bunch in the loop of the duodenum, and ought not to be mistaken for the pancreas.

The stomach and intestine are kept in place and suspended to the dorsal wall of the body-cavity by a delicate membrane, the *mesentery* (Fig. 6, *mes*), which

folded in correspondence with the various coils. As we shall see, the mesentery is really a portion of a thin, moist membrane, the *peritoneum*, with which the body-cavity is lined.

The small intestine becomes continuous posteriorly, with a much wider tube (Figs. 4 and 8, *rct*), lying against the dorsal wall of the abdomen, and called the *large intestine* or *rectum*. It is continued into a short tube, the *cloaca* (Fig. 8, *cl*), which passes backwards, between the backbone above and the pubis below, to open externally by the vent. Thus the mouth-cavity, pharynx, gullet, stomach, small intestine, rectum, and cloaca form a continuous tube, opening externally at each end, by mouth and cloacal aperture respectively, and, for the greater part of its extent, contained within the body-cavity. The whole tube is known as the *alimentary canal* (Lat. *aliment*, food).

Attached to the mesentery, close to the anterior end of the rectum, is a rounded body of a deep-red colour, the *spleen* (Figs. 4 and 8, *spl*). Quite at the posterior end of the abdominal cavity a very thin-walled and transparent sac (*u. bl*) will be seen, connected with the ventral side of the cloaca, and varying much in size according to its state of distension. This is the *urinary bladder* (Fig. 8, *bl*), which communicates by an aperture with the cloaca, and when distended will be seen to be bilobed and of considerable size.

If your specimen should be an adult female, and the time of year approaching the breeding season, you will already have observed, as the most prominent organs in the body, two large, lobed structures of a dark colour, protruding one on either side, and partly obscuring the view of the other organs. Each (Fig. 5, *l. ovy*) contains a great number of small globular bodies, half black and half white, and is suspended to the roof of the body-

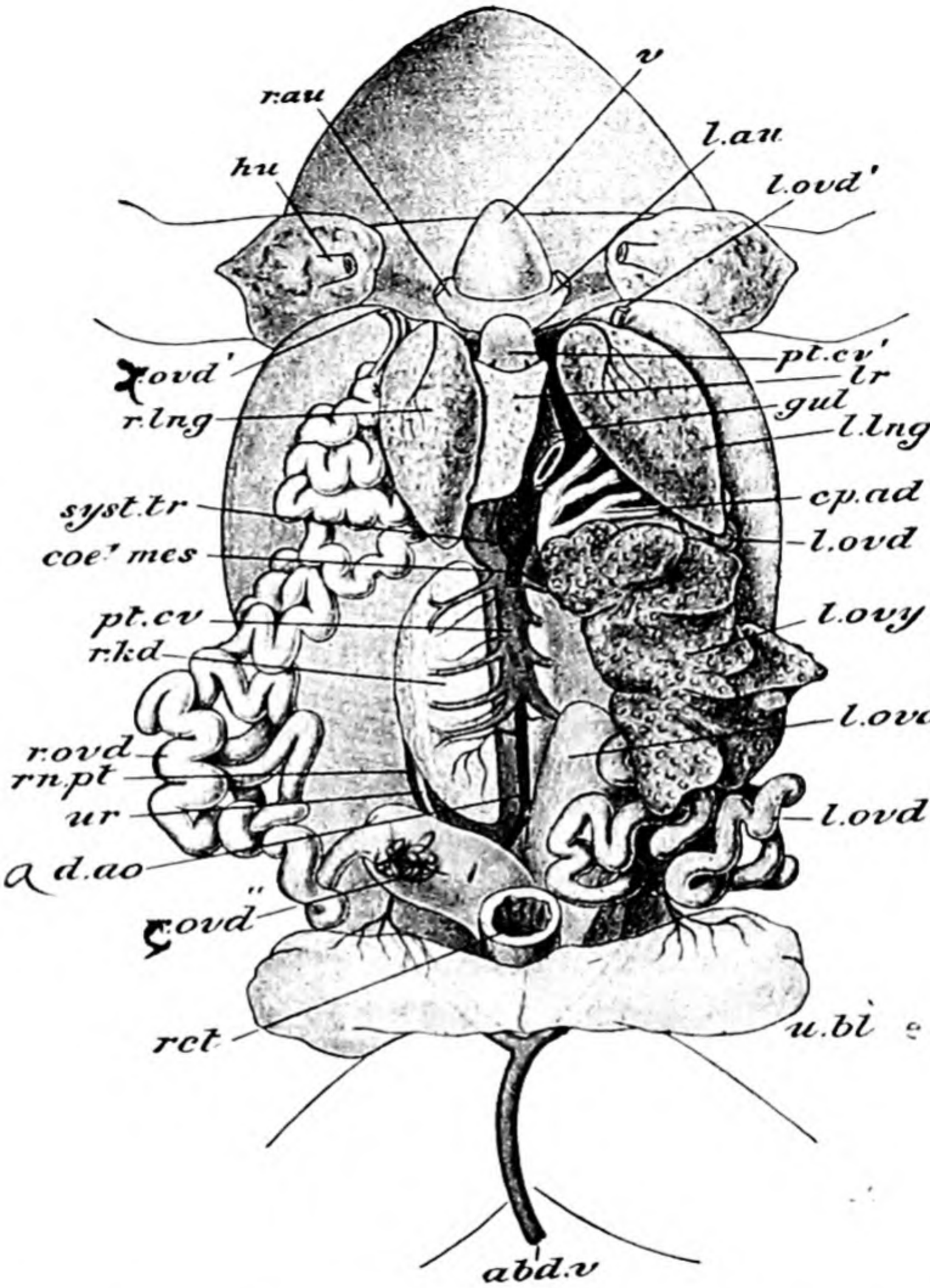


FIG. 5.—Dissection of a young Female Frog (*Rana temporaria*). The gullet (*gul*) and rectum (*rct*) have been cut through, and the alimentary canal removed between these two points. The liver is removed, with the exception of a small portion (*lr*) surrounding the postcaval vein (*pt. cv*). The ventricle of the heart (*v*)

is turned forwards, and the abdominal vein (*abd. v*) is severed and turned backwards. The right ovary and fat-body are removed, and the right oviduct (*r. ovd*) is slightly displaced outwards. (× 1½.)

abd. v. abdominal vein; *cœl. mes.* cœliaco-mesenteric artery; *cp. ad.* corpus adiposum, or fat-body; *d. ao.* dorsal aorta; *gul.* gullet; *hu.* cut end of humerus or upper-arm bone; *l. au.* left auricle; *l. lng.* left lung; *l. ovd.* left oviduct; *l. ovd'.* its opening into the body-cavity; *l. ovd''.* its posterior dilatation; *l. ovy.* left ovary; *lr.* portion of liver; *pt. cv.* postcaval vein; *pt. cv'.* its anterior portion passing between the liver and the heart; *r. au.* right auricle; *rct.* rectum; *r. kd.* right kidney; *r. lng.* right lung; *rn. pt.* renal portal vein; *r. ovd.* right oviduct; *r. ovd'.* its opening into the body-cavity; *r. ovd''.* its posterior dilatation; *syst. tr.* systematic arterial trunks at their point of union; *u. bl.* urinary bladder; *ur.* ureter; *v.* ventricle.

cavity by a sheet of peritoneum. These bodies are the *ovaries*, or organs for producing the eggs; the rounded bodies of which they are largely composed are the *eggs* themselves. To each ovary is attached a yellow structure, produced into a number of streamer-like lobes (*cp. ad*); this is the *fat-body*, which serves as a storehouse of reserve nutriment.

By lifting up either of the ovaries there is seen beneath it—in the natural position of the parts, above or dorsal to it—a greatly convoluted colourless tube (*l. ovd*, *r. ovd*) of about the same diameter as the intestine. This is the *oviduct*, through which the eggs pass from the ovary to the cloaca. If the specimen is allowed to remain long in water the oviducts will be found to swell and finally to become disintegrated; this is due to the fact that in them is formed the jelly in which the laid eggs are enclosed, and which, as already mentioned (p. 9), swells in water.

In the male there is seen, on turning the intestines aside, a pair of yellow ovoidal bodies (Fig. 8, *ts*) about half an inch long, attached by peritoneum to the dorsal wall of the body-cavity. These are the *spermaries* or *testes*; they manufacture the spermatic fluid by which the eggs are impregnated. To the anterior end of each is attached a *fat-body* (*cp. ad*), like that of the female. In young specimens of both sexes the reproductive organs—spermaries, ovaries, and oviducts—are very small.

When the intestine is turned aside there will also be seen, in both sexes, a pair of flattened, irregularly-oval bodies (Figs. 5, *r. kd* and 8, *kd*) lying in the posterior part of the abdominal cavity just above or dorsal to the ovaries or spermaries. These are the *kidneys*. With the outer edge of each is connected a tube, the *ureter* (*ur*), by which the urine, formed in the kidneys, is carried to the cloaca (Fig. 8).

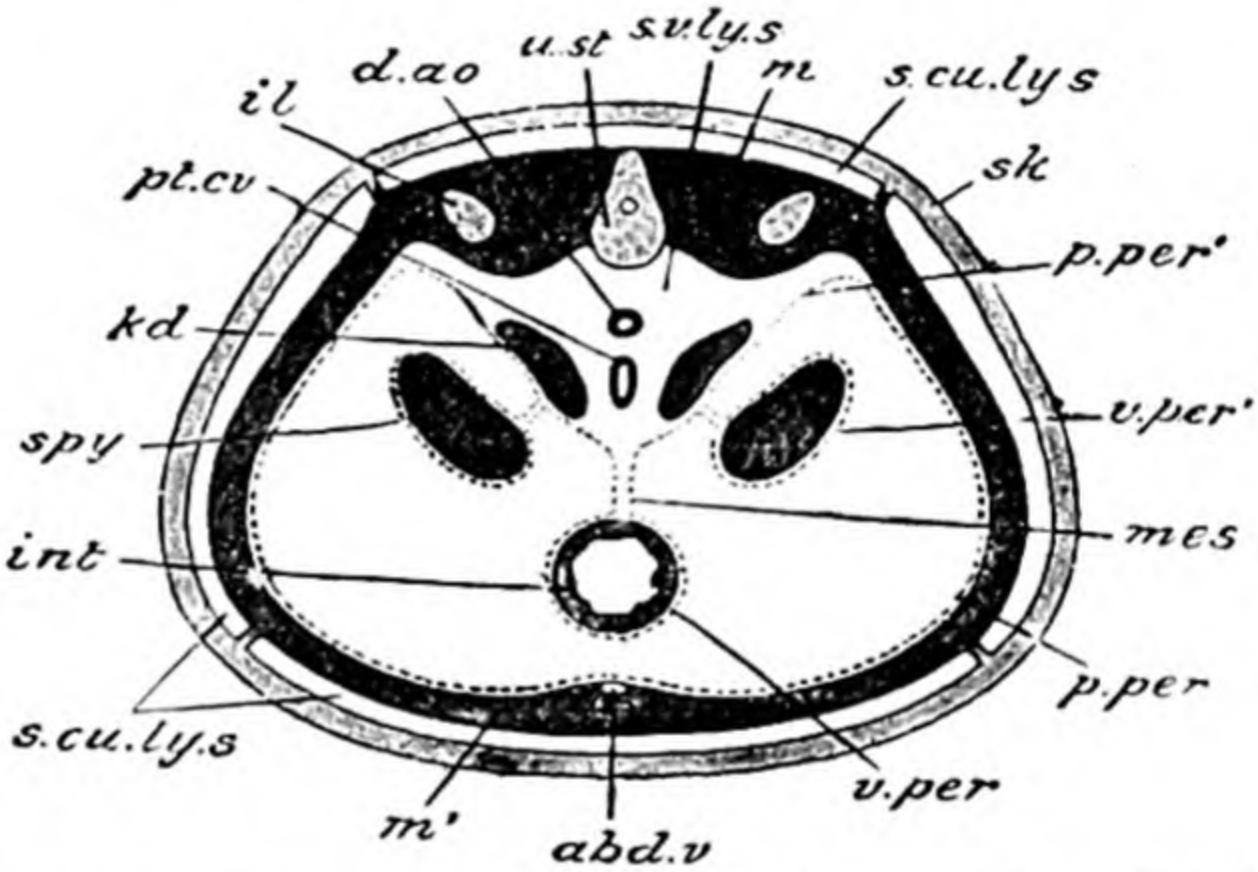


FIG. 6.—Diagrammatic transverse section through the trunk of a Frog, to show the relations of the peritoneum. (× 2½.)

abd. v. abdominal vein; *d. ao.* dorsal aorta; *il.* ileum; *int.* intestine; *kd.* kidney; *m.* muscles of back; *m'.* muscles of abdomen; *mes.* mesentery; *p. per.* parietal layer of peritoneum; *p. per'.* the same, turning down to cover the kidney; *pt. cv.* postcaval vein; *sk.* skin; *s. cu. ly. s.* sub-cutaneous lymph-sinuses; *spy.* spermary; *s. v. ly. s.* sub-vertebral lymph-sinus; *u. st.* urostyle (part of the vertebral column); *v. per.* visceral layer of peritoneum, investing intestine; *v. per'* the same, investing spermary.

It has been pointed out that the abdomen is lined by peritoneum, and that the various organs are suspended by folds of the same membrane, called, in the case of the alimentary canal, the mesentery. The relations of this membrane are best seen in a diagrammatic transverse section of the body (Fig. 6), though many points can be perfectly well made out from the

actual specimen. The body-cavity is lined by what is called the *parietal layer* of the peritoneum (*p. per*), which adheres closely to the body-wall except in the middle dorsal region, where it becomes closely applied to the ventral surface of the kidneys and reproductive organs. Leaving these, the peritoneum of the right side approaches that of the left, and the two, coming into contact, form a double vertical sheet, the *mesentery* (*mes*), which extends ventrally towards the alimentary canal. On reaching the latter, the two layers diverge again and surround the canal, forming the *visceral layer* of the peritoneum (*v. per*). The liver, oviducts, etc., are suspended and covered in the same way. Thus the lining of the body-cavity, the investment of the various organs contained in it, and the folds by which they are suspended, are all parts of one continuous membrane. The space left between the two diverging layers of peritoneum, in the mid-dorsal region, contains lymph, and is known as the *sub-vertebral lymph-sinus* (*s. v. ly. s*).

We have already noticed the abdominal and musculocutaneous veins. Other veins of greater or less size will be seen everywhere, passing, for instance, to the head and limbs (Fig. 4), and in the mesentery. Running parallel with many of the veins are smaller vessels, which are of distinctly stouter texture. These are the *arteries*. They contain little blood in the dead animal, and, owing to the thickness and elasticity of their walls, do not collapse when empty. Hence they are quite easy to see in a frog from which all the blood has been drained, while the thin-walled veins are almost invisible in like circumstances. Finally, there will be seen in many parts of the body, often lying parallel to an artery and a vein, white cords, the *nerves*.

The Neural Cavity and its Contents.—By turning the frog with its back upwards and cutting through

Acc. No: 592

the muscles of the back and the arches of the vertebræ as well as, in front, the roof of the skull (see Fig. 7), you will see that the backbone contains a distinct cavity, the *neural canal*, in which lies a white rod, made of the same soft kind of substance as the nerves, and called the *spinal*

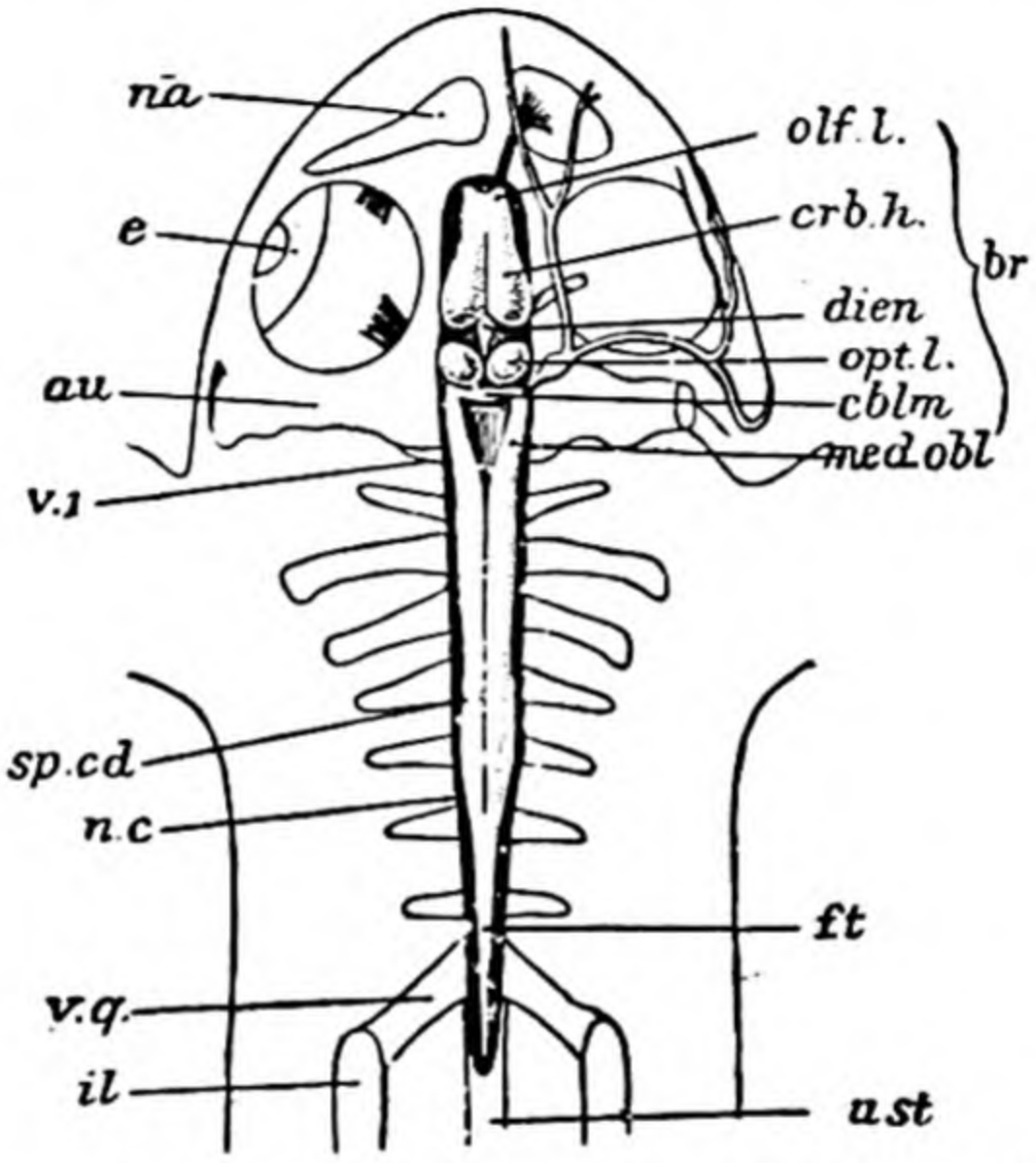


FIG. 7.—Dissection of a Frog in which the entire neural canal (*n. c*) has been opened from above, and the brain (*br*) and the spinal cord (*sp. cd*) laid bare. The brain consists of olfactory lobes (*olf. l*), cerebral hemispheres (*crb. h*), diencephalon (*dien*), optic lobes (*opt. l*), cerebellum (*cblm*), and medulla oblongata (*med. obl*), which will be referred to in Chapter X. The spinal cord ends in a delicate prolongation, the filum terminale (*f. t*). The nasal bones (*na*), eyes (*e*), auditory region of the skull (*au*), transverse processes of the nine vertebræ (*v. 1*—*v. 9*), urostyle (*u. st*) and illa (*il*) are indicated in outline, and serve as landmarks. (× 1½.) (After Howes, slightly altered.)

cord (*sp. cd*), which ends behind in a thread-like prolongation (*f. t*), some distance in front of the thighs. It will also be found that the neural canal is continued, with a slightly increased diameter, into the skull, and that the spinal cord becomes continuous with the *brain* (*br*), a

complex organ formed of several parts, which will be referred to hereafter.

General Structure of the Limbs.—A transverse section cut across one of the legs, at about the middle of the thigh, will show in the middle of the cut surface the thigh-bone, around it the flesh or muscles, and around this again the skin. Similar cuts through various parts of both fore- and hind-limbs show that these appendages of the body are solid, containing no cavities, except the sub-cutaneous lymph-sinuses previously observed.

Summary.—We thus get a notion of the general plan of construction of a frog as follows. It consists of a central or *axial portion*, the head and trunk, and of two pairs of lateral offshoots or *appendages*, the fore- and hind-limbs. The trunk is hollowed out into two cavities: the *body-cavity* (*cœlome*) below, and the *neural canal* above; of these the neural cavity alone is continued into the head. The body-cavity contains the greater part of the alimentary canal, the liver, gall-bladder, pancreas, spleen, lungs, heart, kidneys, urinary bladder, and reproductive organs. The neural canal contains the brain and spinal cord. The anterior end of the alimentary canal is continued forwards into the head, forming the mouth-cavity, and opens externally by the aperture of the mouth; its posterior end opens externally by the vent. The alimentary canal passes through the containing body-cavity, having no communication with it. The lungs open into the pharynx, and thus communicate with the exterior not only by the mouth but also by the nostrils. The kidneys, bladder, and oviducts communicate with the cloaca, and thus with the exterior through the vent. Neither the neural nor the abdominal cavity has any communication with the exterior. The walls of the head and trunk consist largely of bones and muscles covered with skin. The limbs are solid out-

growths of the trunk, formed mainly of muscle, with bony supports and a covering of skin.

Organs.—Notice that the body consists of various definite parts, or *organs* as they are technically termed,

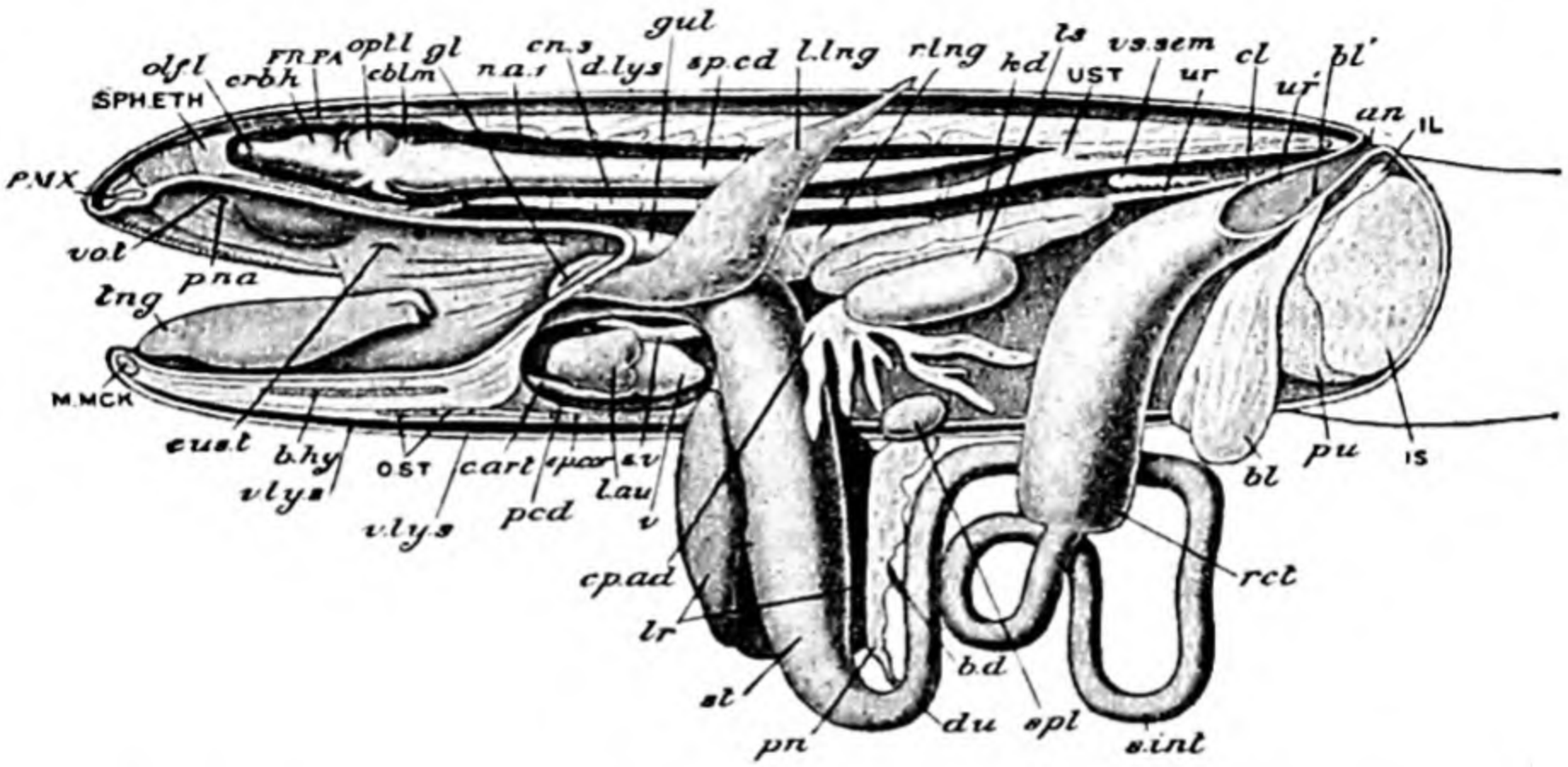


FIG. 8.—Dissection of a Male Frog from the left side. The left fore- and hind-limbs and the left sides of the head and trunk have been cut away, the alimentary canal and liver are displaced downwards, and the mouth, pharynx, and cloaca laid open. (× 1½.)

an. vent; *b. d.* bile-duct; *b. hy.* body of hyoid; *bl.* urinary bladder; *bl'.* its opening into the cloaca; *c. art.* conus arteriosus; *cblm.* cerebellum; *cl.* cloaca; *cn. 3*, centrum of third vertebra; *cp. ad.* fat body; *crb. h.* cerebral hemisphere; *d. ly. s.* dorsal lymph-sinus; *du.* duodenum; *ep. cor.* epicoracoid; *eus. t.* Eustachian tube; *FR. PA.* fronto-parietal; *gl.* glottis; *gul.* gullet; **IL.** ilium; **IS.** ischium; *kd.* kidney; *l. au.* left auricle; *l. lng.* left lung; *lr.* liver; **M.MCK.** mento-meckelian bone; *n. a. 1*, arch of first vertebra; *ol. f.l.* olfactory lobe; *opt. l.* optic lobe; **O. ST.** omosternum; *pcd.* pericardium; *PMX.* premaxilla; *pn.* pancreas; *p, na.* internal nostril; *pu.* pubis; *rct.* rectum; *r. lng.* right lung; *s. int.* ileum; *sp. cd.* spinal cord; **SPH.ETH.** sphenethmoid; *spl.* spleen; *st.* stomach; *s. v.* sinus venosus; *tng.* tongue; *ts.* spermary; *ur.* ureter *ur'.* its aperture into the cloaca; **U.S.T.** urostyle; *v.* ventricle; *v. ly. s.* ventral lymph-sinus; *vo. t.* vomerine teeth; *vs. sem.* seminal vesicle. (From Parker and Haswell's *Zoology*.)

which have various purposes or *functions* to perform. The alimentary canal, together with the liver and pancreas, are *organs of digestion*; the lungs and skin, *organs of respiration* or breathing; the heart and blood-vessels *organs of circulation*, serving as they do to propel

and conduct the blood through the body; the kidneys, aided by the skin, *organs of excretion*, for getting rid of waste matters; the ovaries and spermaries, *organs of reproduction*; the muscles, *organs of movement*; the brain and spinal cord, together with the nerves, *organs of control*, serving to direct or control the actions of the body; the skin, nose, eye, and ear, *sensory organs*, by which communications are kept up with the external world.

Tissues.—Notice also that the various organs of the body are built up of different materials, or *tissues* as they are called. We have already distinguished muscle, bone, cartilage, connective-tissue and nervous tissue. Other tissues we shall meet with in the course of a more careful examination.

CHAPTER III

THE FROG (*continued*) : THE SKELETON

If you have followed the description given in the preceding chapter with a frog before you, testing every statement as you proceeded by reference to the specimen, you will now have a very fair notion of the general build of the animal. The next thing to do is to study its various parts in somewhat greater detail.

As the bones and cartilages form the framework on which all the other parts are supported, it is convenient to begin with them. You may study them on a prepared skeleton, but a far better plan is to make a skeleton for yourself.

Parts of the Skeleton.—The skeleton consists of the following regions :—

1. *The skull* (Figs. 10 and 11) : a complex mass of mingled bone and cartilage, enclosing the brain and the organs of smell and hearing, and supporting the upper jaw. Connected loosely with the skull, but really forming part of it, are the lower jaw and a cartilage in the floor of the mouth known as the *hyoid*.

2. The *vertebral column* or *backbone*, consisting of nine movably united pieces, the *vertebræ* (Fig. 9, v. 1—v. 9), and of a long bony rod, the *urostyle* (UST), representing a number of fused vertebræ belonging to the tail-region of the tadpole.

3. The *shoulder-girdle* or *pectoral arch* (Figs. 13 and 14), an inverted arch of bone and cartilage nearly encircling the anterior part of the trunk and giving attachment to—

4. The bones of the *fore-limbs* (Fig. 16).

5. The *hip-girdle* or *pelvic arch* (Figs. 9 and 17), an apparatus shaped somewhat like a bird's "merry-thought": it is attached in front to the ninth vertebra and behind gives attachment to—

6. The bones of the *hind-limbs* (Fig. 9).

The Vertebral Column.—The essential structure of a vertebra may be best studied by examining any of the vertebræ from the second to the seventh: the first, eighth, and ninth present certain peculiarities, and so may be left till last.

The whole vertebra (Fig. 9, B) has somewhat the form of a signet-ring with its sides produced into two outstanding projections. The part comparable to the stone of the ring is ventral in position, and is called the *body* or *centrum* (*cn*), the form of which is *procœlous*, *i.e.*, its anterior face is concave, its posterior face convex, and both faces are covered with a thin layer of cartilage. The part corresponding with the circle of the ring is the *neural arch* (*pd*, *lm*): it arches over the spinal cord and is produced in the middle line above into a blunt projection, the *neural spine* (*n. sp*). From the arch is given off, on either side, the large outstanding projection already referred to, the *transverse process* (*tr. pr*), which is tipped with cartilage. These cartilaginous epiphyses found upon the distal ends of transverse processes are particularly noticeable in *R. tigrina*, those upon the third vertebra being very large and backwardly directed.

The neural arch gives off from its anterior face, just above the origin of the transverse processes, a pair of small shelf-like projections, the *articular processes* or *zygapophyses* (*a. zyg*). Each has its upper surface flat

and smooth, and covered with a thin layer of cartilage. A similar pair of processes spring from the posterior face of the arch, but have the smooth, cartilage-covered surface or *facet* looking downwards.

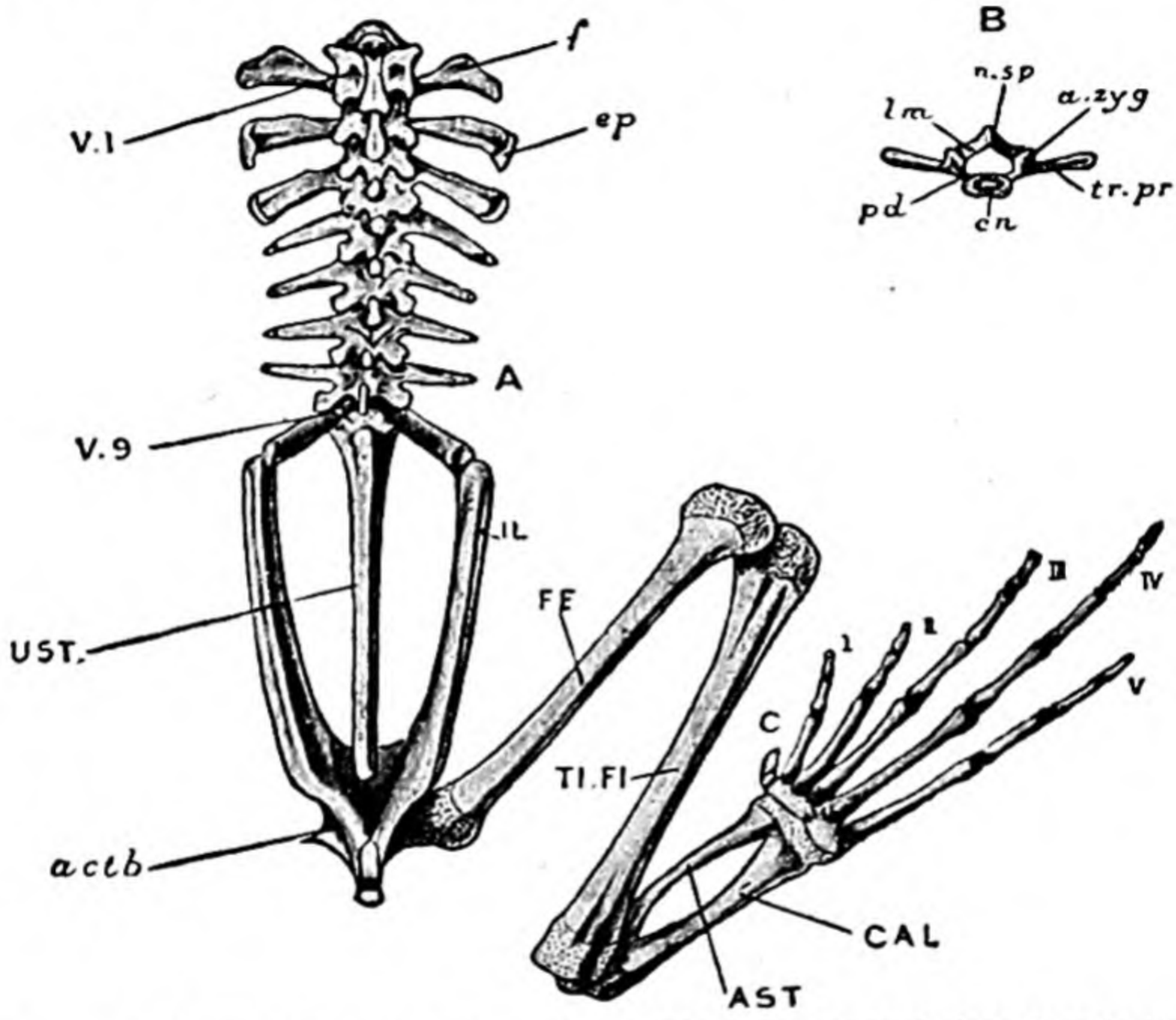


FIG. 9.—A, the vertebral column, hip-girdle and hind-limb of *R. tigrina*; B, anterior face of the fourth vertebra. (B.L.B.)
actb. acetabulum; *ast.* astragalus; *a. zyg.* anterior articular processes or pre-zygapophyses; *C.* calcar; *Cal.* calcaneum; *cn.* centrum; *ep.* epiphyses on the tips of transverse processes; *f.* flange-like projection on the transverse process of the second vertebra; *FE.* femur; *IL.* ileum; *lm.* roof of neutral arch; *n. sp.* neural spine; *pd.* base of neural arch; *TI. FI.* tibio-fibula; *tr. pr.* transverse process; *UST.* urostyle; *v. 1*, first vertebra; *v. 9*, ninth or sacral vertebra; *I—V.* digits.

When two vertebræ are placed in position, the convex posterior face of the foremost centrum fits into the concave anterior face of its successor, like a cup and ball, and at the same time the posterior articular processes of

the first fit over the anterior articular processes of the second. All the touching surface is, as we have seen, covered with cartilage, and the vertebræ can be moved upon one another, either up and down or from side to side.

The centra and articular processes are the only parts of the vetebræ which are in contact when the bones are in their natural positions. The neural arches are, relatively, greatly developed antero-posteriorly in *R. tigrina*. When viewed from above, the vertebral column of this species (Fig. 9) does not show a series of gaps between the arches (as the common European species of frog do), but, on the contrary, there is a very marked overlap of each arch dorsally upon that immediately posterior to it. There are gaps between the sides of the arches, bounded by the articular processes above and the centra below. These are called the *inter-vertebral foramina* : through them the nerves pass from the spinal cord.

The only difference of importance between the vertebræ now under consideration is in the form and direction of their transverse processes, which are specially large in the second, third, and fourth vertebræ.

The first vertebra has no transverse processes, and on either side of the very small " body " its anterior face bears, instead of the ordinary articular processes, a pair of obliquely placed, oval, slightly concave surfaces or facets, covered with cartilage, and serving for the articulation of the condyles of the skull, presently to be described. The transverse processes of the ninth or *sacral* vertebra are very long and strong, directed obliquely backwards, and tipped with cartilage : to them the arms of the hip-girdle are articulated.

The eighth vertebra differs from its predecessors in having its body concave behind as well as in front. Corresponding with this, the ninth (v. 9) has its centrum convex in front,

while behind it presents two little rounded elevations placed side by side.

It will be seen that the vertebræ are all corresponding structures, following one another in a regular series from before backwards. A correspondence of this kind, in which there is a repetition of similar parts along the body, is termed a *serial homology*, and thus not only the vertebræ as a whole, but also their various parts are serially homologous, each to each, the correspondence being disturbed only by the first vertebra, in which the transverse processes are absent and the anterior face is modified for articulation with the skull.

The urostyle (UST) is a long bone with a gradually diminishing ridge along its dorsal surface (see p. 30). Its anterior face has somewhat the appearance of a small vertebra with no transverse processes, and has a double concavity for articulation with the double convexity on the ninth vertebra. Some distance behind the anterior end there is on each side a small aperture, representing an intervertebral foramen, for the last spinal nerve. These foramina are very imperfectly developed, and sometimes absent on one or both sides of the urostyle in *R. tigrina*.

The **skull** is a very complex structure, consisting partly of bone, partly of cartilage. It is divided into the following regions :—

1. The *brain-case* or *cranium*, a sort of oblong box containing the brain (Figs. 10 and 11) : it forms the middle portion of the skull and is a direct forward continuation of the vertebral column.

2. The *auditory capsules*, a pair of outstanding masses arising, right and left, from the posterior end of the brain-case. They lodge the organs of hearing.

3. The *olfactory capsules*, smaller masses proceeding from the anterior part of the brain-case and united

with one another in the middle line. They lodge the organs of smell.

4. The *suspensoria* (*q*), a pair of projections springing from the outer and upper portions of the auditory capsules, and directed downwards, outwards and backwards. To them the ends of the lower jaw are attached.

5. The *upper jaw*, a half-circle of bone and cartilage, united in front to the olfactory capsules and behind to the suspensoria. On either side of the skull, between the cranium and upper jaw, is a large space, the *orbit*, in which the eye is contained.

6. The *lower jaw*, a roughly semicircular bar of bone and cartilage, articulated at its ends with the suspensoria.

7. The *hyoid* (Fig. 8, *b. hy*), a shield-shaped cartilage connected by delicate curved rods with the auditory capsules.

On the posterior surface of the brain-case is a large hole, the *foramen magnum* (Fig. 10, A), on either side of the lower edge of which is a large oval elevation covered with cartilage, the *occipital condyle*. The foramen magnum leads into the cavity in which the brain is contained. If the first vertebra is placed in its natural position with regard to the skull it will be seen that the foramen magnum corresponds with the neural canal of the vertebra, and that the condyles fit into its articular surfaces. Thus the skull readily moves up and down upon the vertebra, the condyles acting as rockers; a space between the neural arch and the dorsal edge of the foramen magnum covered by membrane in the fresh state allows of the requisite amount of play.

The discrimination of the separate bones and detailed structure of the skull is rather difficult, and may very well be omitted by the beginner at the present stage.

The occipital condyles are borne on a pair of irregular bones (*eo*), which bound the sides of the foramen

magnum, nearly uniting above and below it, and extending over a considerable portion of the posterior surface of the auditory capsule. These bones are the

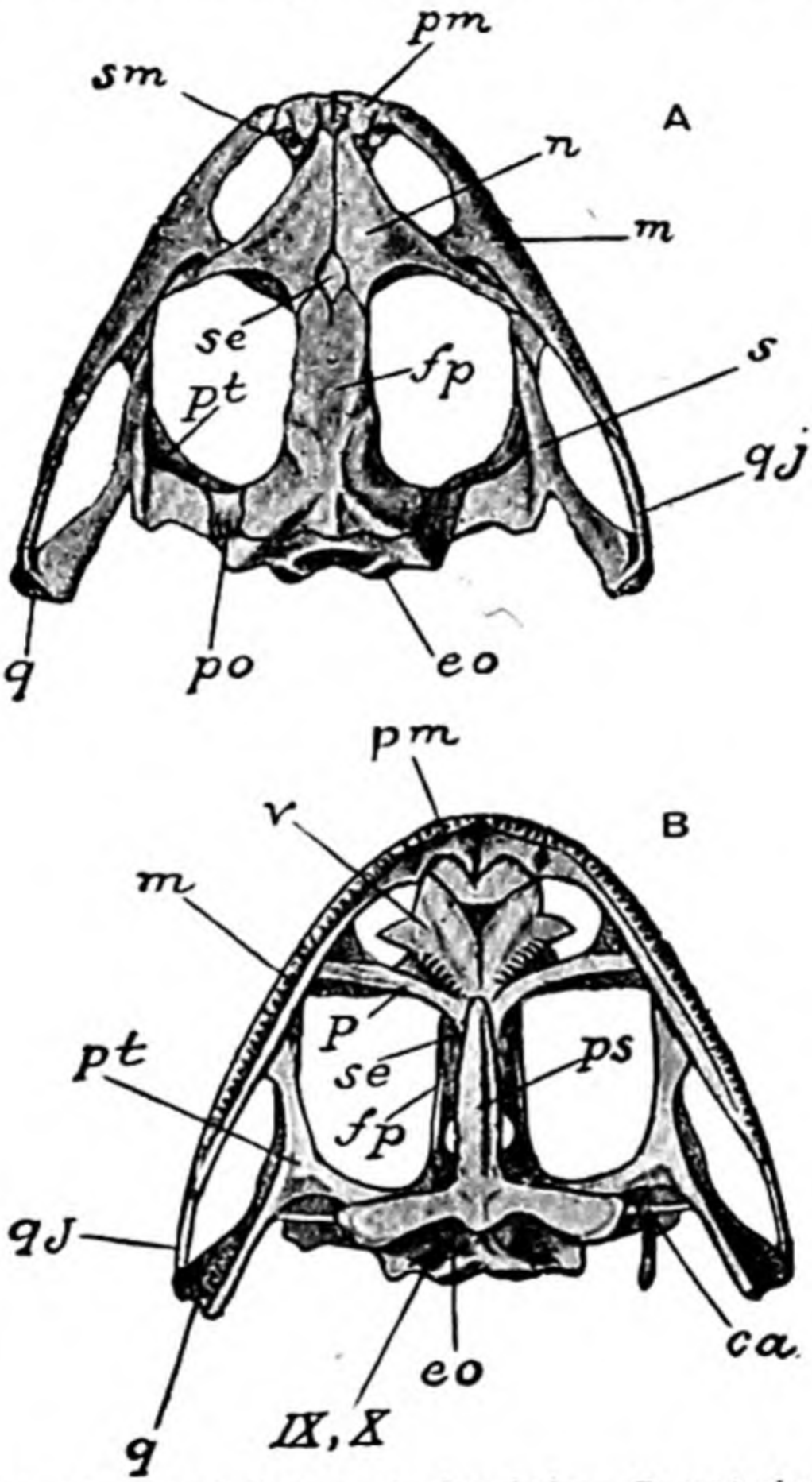


FIG. 10.—Skull of *R. tigrina*. A, dorsal view; B, ventral view.
c.a. columella auris; *eo.* exoccipital; *fp.* fronto-parietal; *m.* maxilla; *n.* nasal; *p.* palatine; *pm.* premaxilla; *po.* pro-otic; *ps.* parasphenoid; *pt.* pterygoid; *q.* quadrate cartilage; *qj.* quadrato-jugal; *s.* squamosal; *se.* sphenethmoid; *sm.* septo-maxillary; *v.* vomer; IX, X, foramen for the exit of ninth and tenth nerves. (After Bhatia and Parshad.)

exoccipitals. The exoccipital is perforated just in front of the condyle, by an aperture (Fig. 10, B, *ix*, *x*) through which two nerves, the glossopharyngeal and the vagus, pass on their way from the brain. In front of each exoccipital is another irregular bone (*po*) forming a considerable portion of the roof and anterior wall of the auditory capsule, and called the *pro-otic*. Each pro-otic is separated from the corresponding exoccipital, in young frogs, by a band of cartilage, but in old specimens the two bones are more or less completely united. Dorsally, each presents a quadrilateral area between the fronto-parietal and exoccipital on the inner side and the inwardly directed horizontal flange of the squamosal which partly overlaps it, on the outer. Anteriorly, the pro-otic bone forms nearly the whole of the anterior wall of the auditory capsule; a small area on the outer side of this anterior wall remains cartilaginous. On the inner side, this anterior portion curves forward to form the posterior part of the inner wall of the orbit. In this angle is situated the foramen for the exit of the trigeminal, abducent, and facial nerves (Fig. 11, B, *v*, *vii*).

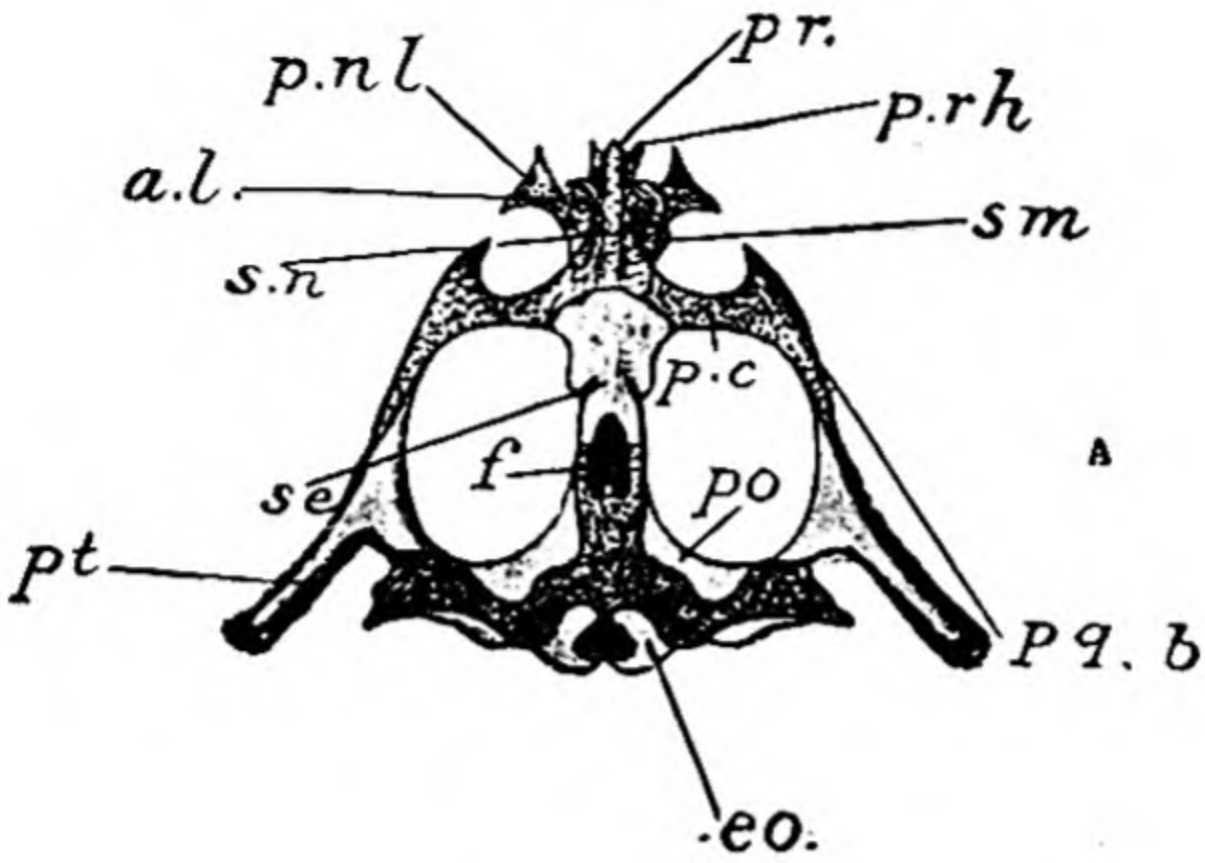
In the disarticulated skull it can be made out that the exoccipital and pro-otic of either side enclose a cavity; in this the organ of hearing is contained. The ventral and the posterior walls of the auditory capsule are cartilaginous.

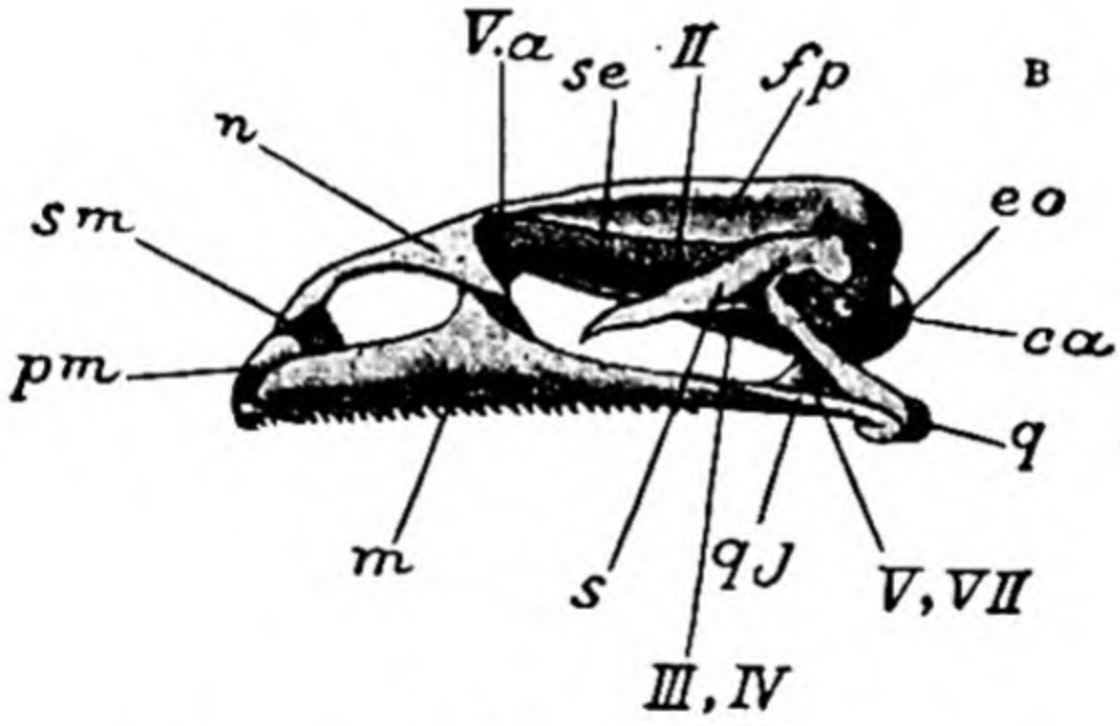
The dorsal surface of the brain-case is covered by two longish, flat bones (*fp*). In the young condition each of these consists of two distinct bones, the front one the *frontal*, the hinder the *parietal*. As the young frog grows the frontal and parietal of either side become completely fused, forming a single *fronto-parietal*. In this species, the fronto-parietals form a strong roof to the skull, with a notch in front, the remains of the frontal suture, but are wholly coalesced beyond this; they end

behind in two broad wings which spread over the hinder region of the cranium almost to the end. On the upper surface of the olfactory capsules are large, broad-based, triangular bones, the *nasal* (*n*) meeting each other in the median line and diverging posteriorly to meet the anterior ends of the fronto-parietals, thus leaving exposed a diamond-shaped area of the sphenethmoid.

The ventral surface of the brain-case is covered by a single strong bone (*ps*) having the shape of a T. The stem extends forwards in the middle line as far as the olfactory capsules, while the arms stretch outwards beneath the auditory capsules. This very characteristic bone is the *parasphenoid*. Its posterior border is deeply concave and bears a short median process. The stem or the longitudinal arm of the bone, besides forming the floor, rises up on each side to form a portion of the lateral wall of the cranium. On the under surface of the olfactory capsules, corresponding to the nasals above, are a pair of irregular bones, the *vomers* (*v*). They meet each other in the middle line posteriorly, but diverge anteriorly, leaving a portion of the floor of the olfactory capsules uncovered. Their outer edges are notched and help to bound the internal nostrils: their posterior borders bear the vomerine teeth.

The anterior end of the brain-case is surrounded by a bone (*se*) which extends forwards into the region of the olfactory capsules, and is partly covered by the fronto-parietals and nasals above and by the parasphenoid below. This is the *girdle-bone* or *sphenethmoid*. In the disarticulated skull it is seen to have a very peculiar shape. Its posterior half encloses a single cavity in which the fore-end of the brain (Fig. 11, A, *se*) is lodged. Its anterior half encloses two cavities, right and left, separated from one another by a vertical partition, and serving to lodge the posterior ends of the olfactory





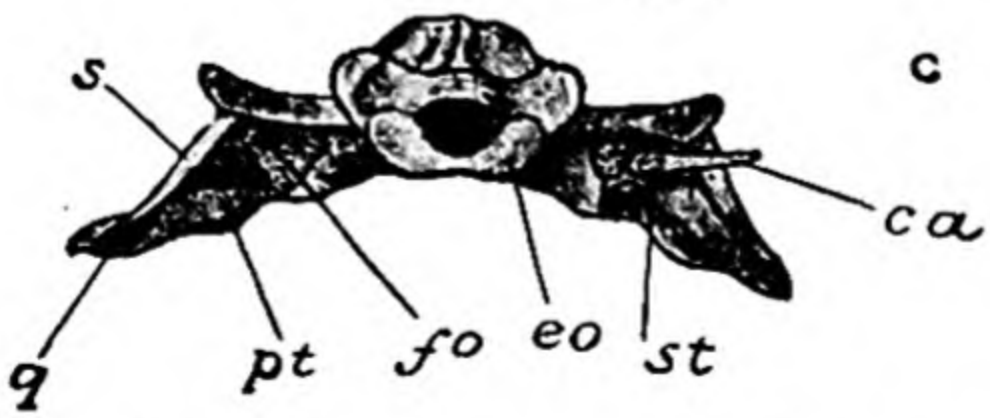


FIG. 11.—Skull of *R. tigrina*. A, Dorsal aspect of skull after removal of investing bones; B, from the left side; C, from behind.
a.l., *p.nl.*, *p.r.*, *p.rh.* different processes of the cartilages of the olfactory capsule; *f.* fontanelle; *f.o.* fenestra ovalis; *p.c.*, *pq.b.* palato-quadrate bar of cartilage; *s.n.* septum nasi; *II*, *III*, *IV*, *V*, *VII*, foramina for the exit of the cranial nerves. Other letters as in the previous figure. (After Bhatia and Parshad.)

sacs or organs of smell. Each of these cavities communicates with the single posterior cavity by a small hole through which the nerve of smell passes. Towards the anterior end, the bone extends on either side so as to form a part of the anterior boundary of the orbit. In the dorsal view a lozenge- or diamond-shaped area of this bone (Fig. 10, A, *se*) is seen, as noticed above, between the nasals in front and the fronto-parietals behind.

Between the girdle-bone in front and the pro-otic behind, the side-walls of the skull are formed of cartilage perforated by a rounded aperture, the *optic foramen* (Fig. 11, B, *II*), for the nerve of sight.

Forming the outer part of the suspensorium is a hammer-shaped bone, the *squamosal* (*s*); its head is applied to the auditory capsule and projects forwards into the orbit. From the posterior half of this cross-bar is given off a horizontal shelf-like process partly covering the auditory capsule and extending inwards as far as the junction of the pro-otic and the exoccipital.

The upper jaw is formed of three bones on either side. In front is the *premaxilla* (*pm*), a short bone, sending off an upward process towards the nostril. Next follows the *maxilla* (*m*), a long, curved bone, forming the greater part of the upper jaw, and joined at its posterior end to a small, slender bone, the *quadrato-jugal* (*qj*), which is firmly connected with the lower end of the suspensorium. Both premaxilla and maxilla are produced below into a prominent edge from which spring a number of small conical teeth, arranged in a single row.

Besides these three bones there are two others which seem, as it were, to brace the upper jaw to the brain-case and suspensorium. The *palatine* (*p*) is a narrow, rod-like bone, placed transversely behind the olfactory capsule. The *pterygoid* (*pt*) is a large three-rayed bone;

one ray is directed forward and connected with the outer end of the palatine and with the inner face of the maxilla; another passes backwards and inwards and is connected with the auditory capsule; the third extends backwards and outwards and forms the inner and ventral portion of the suspensorium. The main mass or core of the suspensorium, between the squamosal outside and the pterygoid within, is a rod of cartilage (*q*), which is continued forwards by a bar (*pc*, *pq.b*) supporting the pterygoid and palatine.

There is an important distinction to be drawn between the bones of the skull which can be made out only by the exercise of a good deal of care and patience. By softening the connective-tissue which binds the bones together, it is possible to remove the majority of them without injuring the underlying cartilage (compare Fig. 11, A), provided, of course, that the operation is skilfully performed: these bones are the nasals, vomers, fronto-parietals, parasphenoid, pre-maxillæ, maxillæ, quadrato-jugals, palatines, pterygoids, and squamosals. A sort of foundation or groundwork is then left behind, consisting mainly of cartilage, but containing the exoccipitals, pro-otics, and sphenethmoid. These five bones cannot be removed without pulling the cartilaginous groundwork or *chondrocranium* to pieces. We thus get a distinction between *replacing bones* (so called *cartilage bones*) which take the place of pre-existing cartilage, being therefore continuous with the remaining cartilage and forming part of the chondrocranium, and *investing bones* (so called *membrane bones*) which form no part of the original chondrocranium, being united to it by connective tissue only.

The chondrocranium has a cartilaginous roof, underlying the fronto-parietals; it is pierced by one large (Fig. 11, A. *f*) space, called the *fontanelle*, covered by membrane. It has also a cartilaginous floor (Fig. 10, B) underlaid by the parasphenoid. The olfactory capsules also have a cartilaginous roof and floor of irregular form, with the posterior end of which is united the cartilaginous *palato-quadrate* bar (*pc*, *pq.b*), with which the palatine and pterygoid bones are connected. Posteriorly this bar is continuous with the cartilaginous groundwork (*quadrate*) or core of the suspensorium (*q*), which unites above with the auditory

capsule and below furnishes an articular surface for the lower jaw.

Notice that in describing the vertebral column no distinction was drawn between replacing and investing bones. As a matter of fact the vertebræ and the urostyle are all replacing bones; each consists, in the tadpole, of cartilage which is subsequently replaced by bone.

The **lower jaw** consists of two halves, or *rami*, united with one another in front by ligament. At its posterior end each half bears on its upper surface a shallow pit, by which it articulates with the suspensorium, and a little in advance of this pit is an elevation of the dorsal edge of the jaw, called the *coronary process*.

Each half of the lower jaw consists of a cartilaginous core, the *mandibular* or *Meckel's cartilage*, which furnishes the articular surface referred to, and in front is ossified as a small replacing bone, the *mento-meckelian*. Outside the cartilage are two investing bones. One, the *angulo-splenial*, extends along the inner surface and lower edge of the jaw and forms the coronary process, while the *dentary* forms the outer surface of the anterior half of the jaw.

A feature worth noticing is the presence of three well-marked depressions on the ventral side of the upper jaw in its anterior portion. The middle one of these depressions is between the two premaxillæ and receives a corresponding median projection from the mento-meckelians. The two lateral depressions are at the junction of the premaxilla with the maxilla of each side and accommodate a strongly developed projection of the dentary of each side.

The **hyoid** is a thin, shield-shaped plate of cartilage (Fig. 8, *b. hy*) produced, both in front and behind, into a pair of processes or *horns*, as well as into less important offshoots. The *anterior horns* are long, delicate, cartilaginous rods which curve backwards and then upwards, finally joining with the auditory capsules. The *posterior horns* are short, bony rods

which pass backwards, diverging as they go, one on either side of the glottis.

Two apparently insignificant structures connected with the skull must be described because of their connection with the organ of hearing. Behind the suspensorium is a recess, roofed over by the squamosal, and, in the entire frog, converted by muscle and other tissues

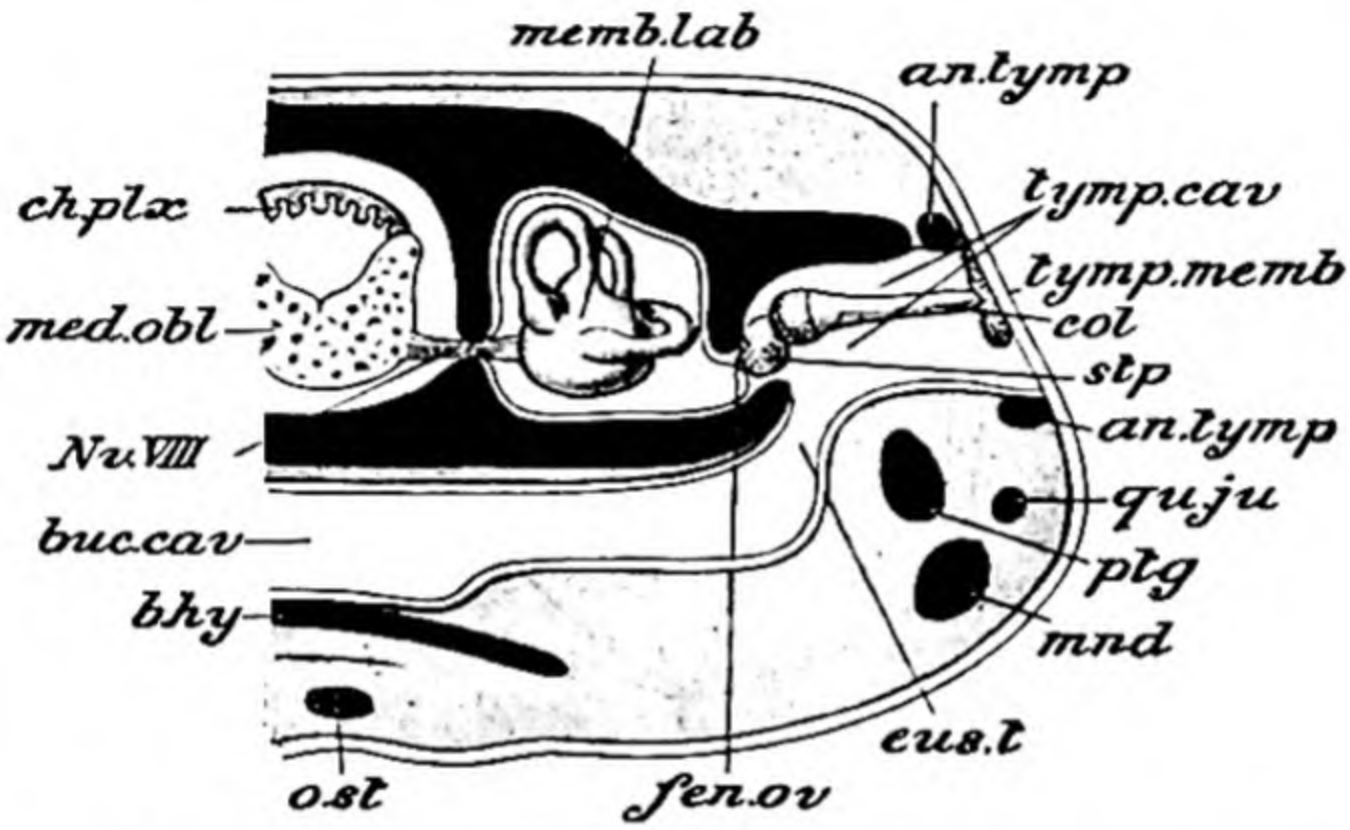


FIG. 12.—Transverse section (diagrammatic) through the head of a Frog at the level of the tympanic cavity. The various parts of the skull shown in section are black, the muscles, &c., grey, and the skin and mucuos membrane white. (× 5.)
an. tymp. tympanic ring; *b. hy.* body of hyoid; *buc. cav.* mouth cavity; *ch. plx.* choroid plexus; *col.* columella; *eus. t.* Eustachian tube; *fen. ov.* fenestra ovalis; *med. obl.* medulla oblongata; *memb. lab.* membranous labyrinth; *mnd.* mandible; *Nv. VIII.* auditory nerve; *o. st.* omosternum; *ptg.* pterygoid; *qu. ju.* quadrato-jugal; *stp.* stapedial plate; *tymp. cav.* tympanic cavity; *tymp. memb.* tympanic membrane. (From Parker and Haswell's *Zoology*.)

into a chamber, the *tympanic cavity* (Fig. 12, *tymph. cav*), bounded externally by the tympanic membrane, and communicating with the mouth-cavity by the Eustachian tube. Supporting the tympanic membrane, as the frame of a tambourine supports the parchment, is a cartilaginous framework of the shape of a short truncated cone, broad outwards and narrowing towards the inner side, which is called the *tympanic ring* (*an. tymp*, shown in

section). Stretching across the tympanic cavity from the outer wall of the auditory capsule to the tympanic membrane is a small, hammer-shaped rod, the *columella* (Figs. 10, 11, *ca*, and 12, *col*), having a bony handle and a cartilaginous head, the latter firmly fixed to the inner face of the tympanic membrane. The inner end of the handle is tipped with cartilage, and is attached to a small cartilaginous nodule, the *stapedial plate* (*st*), which is inserted into an aperture in the auditory capsule known as the *fenestra ovalis* (*fen. ov*). With care the columella, in a wet skull, may easily be removed

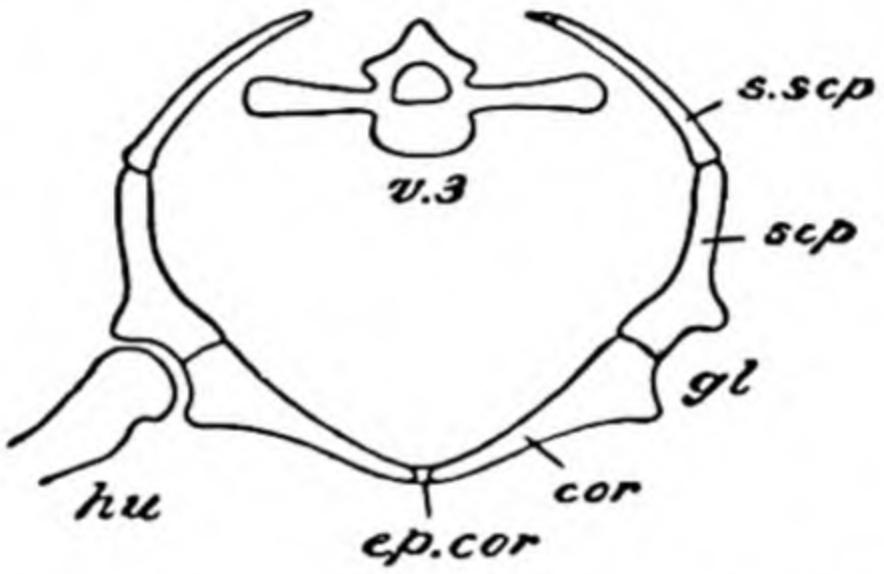


FIG. 13.—Diagrammatic transverse section through the shoulder-girdle of a Frog. (× 2.)
cor. coracoid; *ep. cor*. epicoracoid; *gl*. glenoid cavity; *hu*. humerus; *scp*. scapula; *s. scp*. supra-scapula; *v. 3*, third vertebra.

with small forceps, and examined under a magnifying glass.

The **shoulder-girdle** has the form of an inverted arch encircling the anterior region of the trunk, and having its dorsal ends turned inwards so as partly to cover the second to the fourth vertebræ (Figs. 13 and 14). The dorsal region, on either side, is formed by a broad plate, the *supra-scapula* (*s. cp*). It is mostly formed of bone, but its free edge consists of cartilage which, when dried, is seen to be impregnated with a granular deposit of lime-salts. This rough, brittle tissue is called *calcified*

cartilage, and is distinguishable from bone, which has usually a smooth, enamelled surface.

Connected with the ventral end of the supra-scapula and passing vertically downwards is a flat bone, broadened at each end, the *scapula* (Fig. 13, *scp* : Fig. 14,

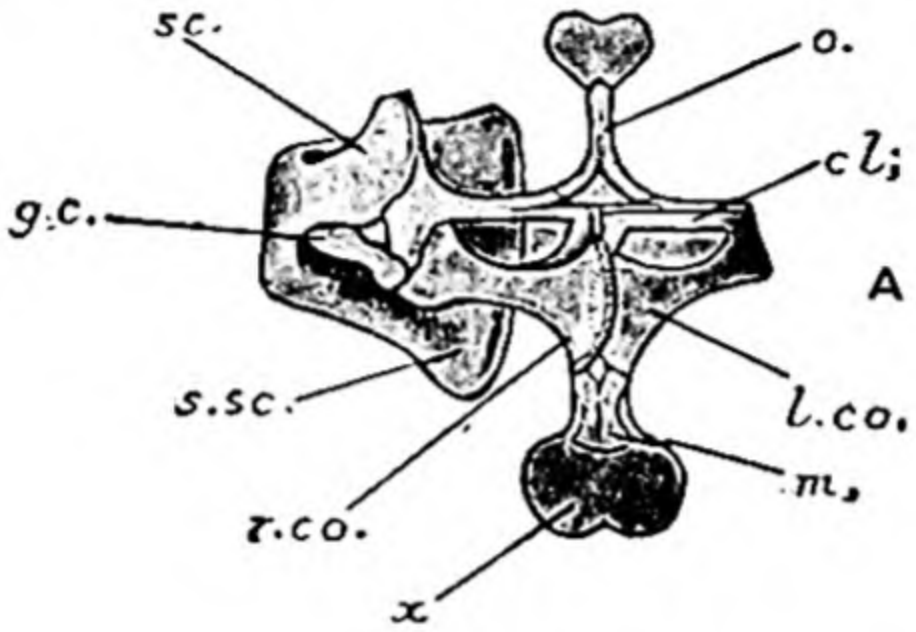


FIG. 14.—The Shoulder-girdle and Sternum of *R. tigrina*. A. Ventral view; B, Dorsal view. (B.L.B.)
cl. clavicle; *m.* metasternum; *o.* omosternum; *pr. co.* precoracoid; *r. co., l. co.* right and left coracoids; *sc.* scapula; *s. sc.* supra-scapula; *x.* xiphisternum.

sc). From its lower end two bones (Fig. 14, *p. co*, *l. co*) pass directly inwards, parallel with one another, and are connected together in the middle line of the chest with their fellows of the opposite side through thin strips of cartilage called *epicoracoids*. The more anterior of these

(*p. co.*) is the precoracoid, a narrow, transverse rod of calcified cartilage which is covered over antero-dorsally with a thin investing bone, the *clavicle* (*cl*). The posterior one is broader and is known as the *coracoid* (*r. co.*, *l. co*). In most species of frog the epicoracoids meet each other in the median line, but in *Rana tigrina* the inner ends of the coracoids, which are covered by thin strips of cartilage, overlap each other, the right lying ventral to the left, though the opposite condition is also sometimes met with. Between the scapula on the one hand and the clavicle and coracoid on the other, there is a cartilaginous interval, the posterior edge of which is scooped out into a depression, the *glenoid cavity* (Fig. 13, *gl*), for the articulation of the upper-arm bone.

Connected with the median ventral portion of the shoulder-girdle is the *sternum*, or breast-bone, which consists of two separate parts, one extending forwards, the other backwards, in the middle line, and each formed of a flattened bony rod (Fig. 14, *o* and *m*, *x*), tipped with a flat plate of cartilage. The sternum of the frog is not homologous with that of mammals as it is not derived from the separated off ventral ends of the ribs.

The anterior bony rod with its terminal cartilage is called the *omosternum* (*o*), the posterior bony rod the *metasternum* (*m*), and the bilobed cartilage at its end the *xiphisternum* (*x*).

All the bones of the shoulder-girdle and sternum are replacing bones except the clavicle.

The Fore-limb.—The upper arm is supported by a single bone, the *humerus* (Fig. 16, *h*), the first example we have had of what is conveniently called a *long bone*. It consists of a roughly cylindrical *shaft*, formed of dense bone, and of two *extremities*—the proximal of partially calcified cartilage, the distal of spongy or cancellated bone. The proximal extremity or *head* is

convex; and fits into the glenoid cavity of the shoulder-girdle (Fig. 13, *gl.*); the distal extremity or *condyle* is almost globular, and is articulated with the bone of the fore-arm.

In a longitudinal section of the humerus which has not been allowed to dry you will see that the shaft (Fig. 15, A, *sh*) is not a solid rod, but a tube, containing a

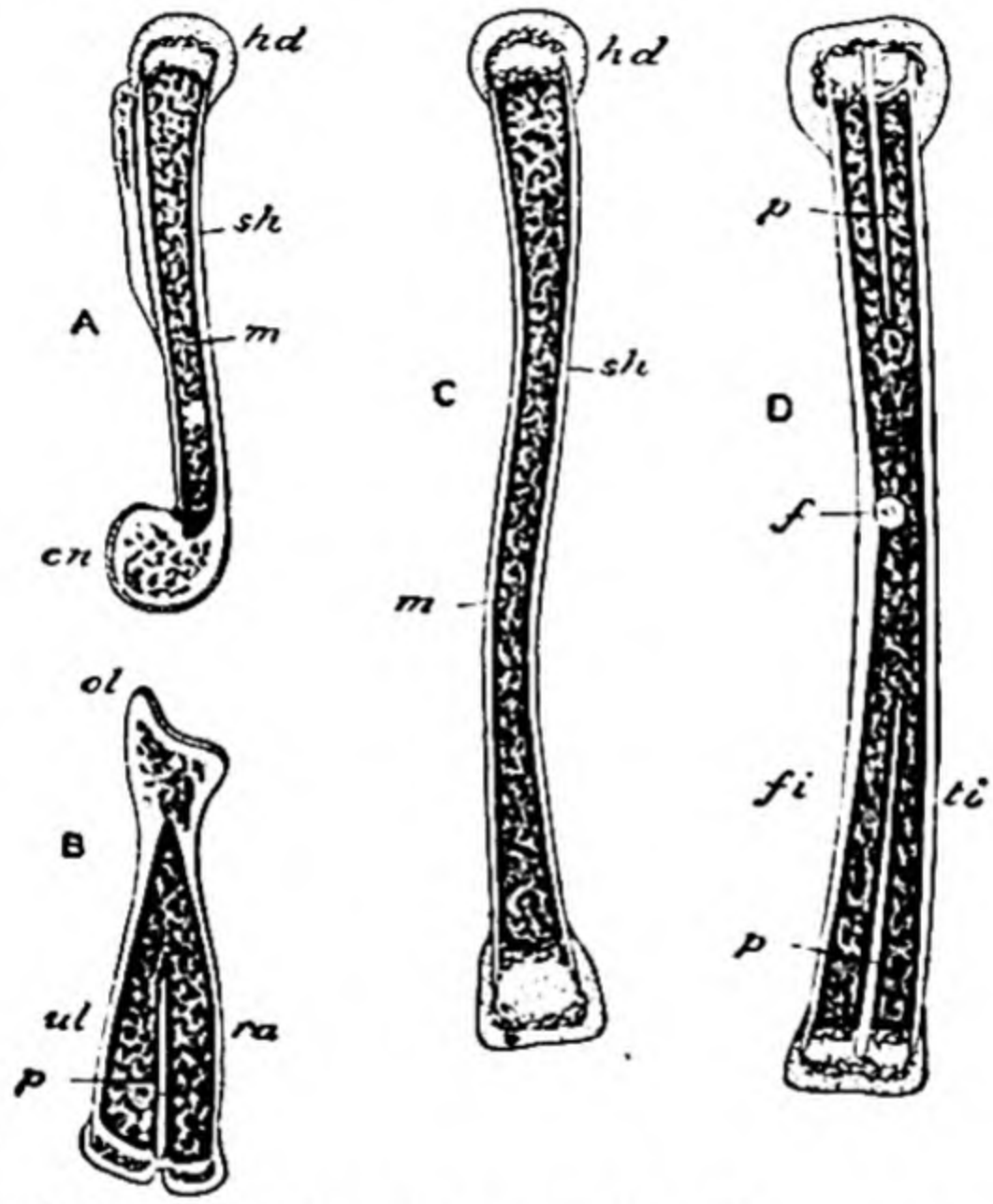


FIG. 15.—Longitudinal sections of the principal long bones of a Frog. (× 2½.) A, humerus; B, radio-ulna; C, femur; D, tibio-fibula; *cn.* condyle; *f.* foramen for artery; *fi.* fibula; *hd.* head; *m.* marrow; *ol.* olecranon process; *p.* bony partition; *ra.* radius; *sh.* shaft; *ti.* tibia; *ul.* ulna.

cavity, the *marrow-cavity*. In this way the weight of the bone is diminished without its strength being impaired. The marrow-cavity contains a substance called *bone-marrow*, composed chiefly of connective-tissue and fat, with blood-vessels. The proximal end of the hollow

shaft is, as it were, plugged by the cartilaginous extremity.

The fore-arm is also supported by a single bone, the *radio-ulna* (Fig. 15, B; Fig. 16, *r.u*). Its proximal end is concave and articulates with the almost globular condyle of the humerus: the outer or posterior edge of the concavity is produced into a short process, the *olecranon* or elbow. The distal end is incompletely divided into two articular surfaces, and between these is a groove passing for some distance towards the

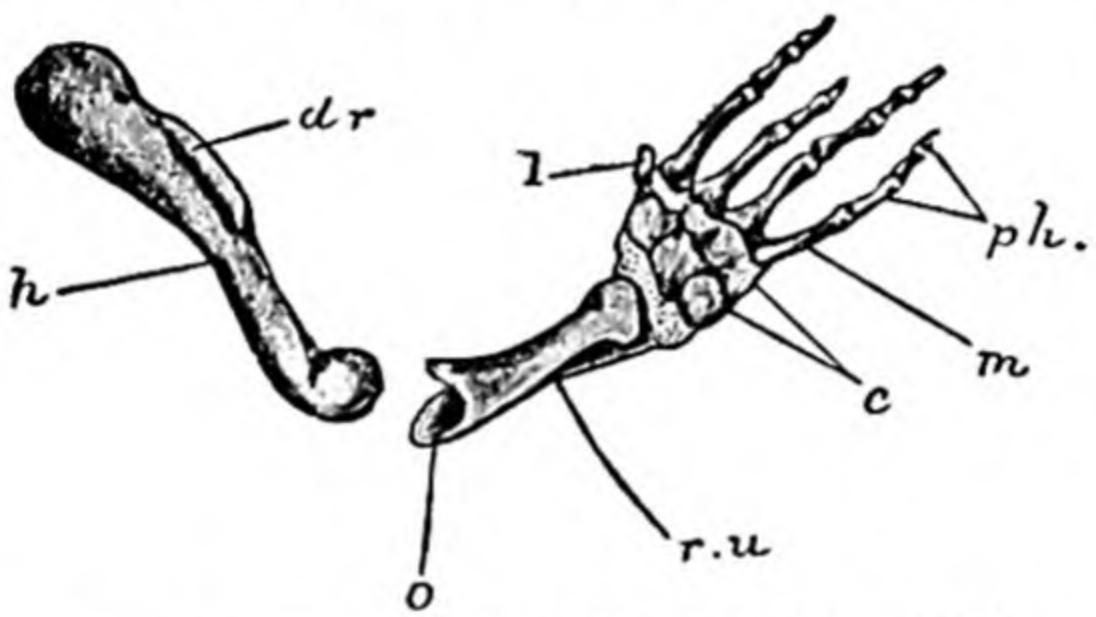


FIG. 16.—The Fore-limb of *R. tigrina*. (B.L.B.)
c. carpus; *d. r.* deltoid ridge; *h.* humerus; *m.* one of the metacarpals; *o.* olecranon process of ulna; *ph.* phalanges; *r.u.* radio-ulna; *I.* rudimentary metcarpal of the first digit.

proximal end of the bone. A section shows that at this end there are two distinct marrow-cavities, indicating that the bone is really double. That this is the case is proved by the examination of a very young frog, in which the single fore-arm bone is represented by two distinct cartilages, the *radius* on the inner or thumb side, and the *ulna* on the outer or little-finger side. The olecranon is a process of the ulna.

The skeleton of the hand is divisible into three regions: the *carpus* or wrist, the *metacarpus* or mid-hand, and the *phalanges* or finger-bones. The carpus consists of six small irregular bones, arranged in two rows (Fig. 16).

The proximal row articulates with the radio-ulna, while to the distal row are attached the *metacarpals*, which together constitute the *metacarpus*. Four of these are long, rod-like bones and support the bases of the four fingers or digits: to them are attached the phalanges, of which the first or innermost digit (II) has two, the next two, and the remaining two digits three apiece. A very small metacarpal, with a single phalanx (I), occurs on the radial side and is concealed by the skin in the entire frog: it corresponds with our own thumb, so that the apparent first digit of the frog is really the second or index finger.

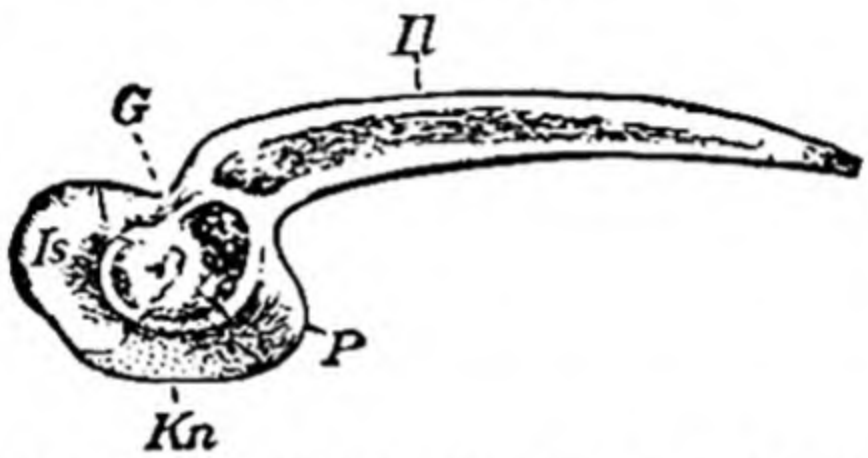


FIG. 17.—The hip-girdle of a Frog seen from the right side. (× 2. *G*. acetabulum; *Kn*. pubis; *Il*., *P* ilium; *Is*. ischium. (From Wiedersheim's *Comparative Anatomy*.)

The Hip-girdle.—This, as we have seen, has somewhat the form of a bird's merrythought. It consists of two long arms (Fig. 9, IL; Fig. 17, *Il*), which are articulated with the transverse processes of the ninth vertebra, and sweeping backwards, unite in a disc-shaped mass, having on either side of it a deep, hemispherical cavity, the *acetabulum* (Fig. 9, *actb*; Fig. 17, *G*), for the articulation of the thigh-bone.

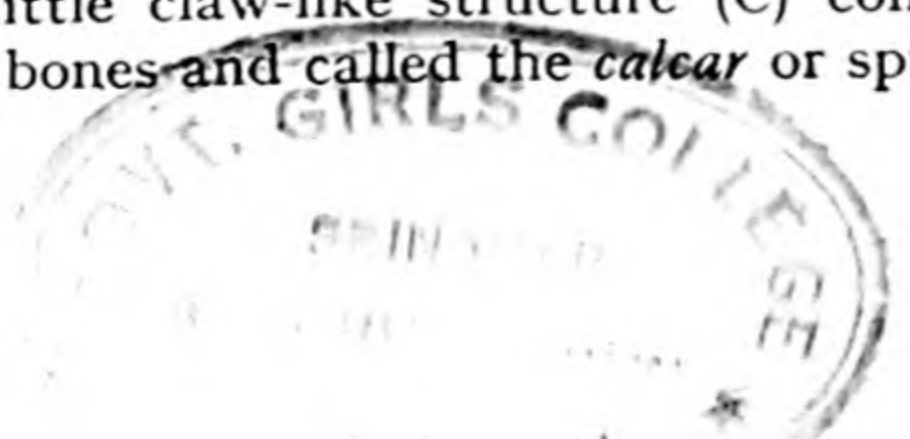
Two *sutures*, or lines of separation, nearly at right angles to one another, divide the disc-shaped portion into three parts. One of these, dorsal and anterior in position, is continued into one of the arms of the hip-girdle and forms half of the acetabulum; this is the

ilium (Fig. 17, *Il*, *P*). The second, posterior in position, is the *ischium* (*Is*); like the ilium, it is made of true bone. The third, or *pubis* (*Kn*), is ventral, and is formed of calcified cartilage. Originally each of these elements is paired, *i.e.*, there is an ilium, an ischium, and a pubis on either side, the three together forming the *innominate*; but in the adult the right and left ischia and pubes become united in the median plane, the ilia only remaining free.

The Hind-limb.—The thigh, like the upper arm, is supported by a single long bone, the *femur* (Fig. 9, FE; Fig. 15, C), having a gently curved shaft and extremities of calcified cartilage. Its rounded proximal extremity, or *head*, fits into the acetabulum : its distal end articulates with the single bone of the shank, the *tibio-fibula* (TI. FI). This, the longest bone in the body, also has a shaft and extremities, and is further distinguished by grooves running from each end towards the middle of the shaft. Sections show that the grooved portions of the bone contain a double marrow-cavity (Fig. 15, D), and in the young animal there are found two shank-bones which afterwards unite, the *tibia* on the inner side, the *fibula* on the outer side.

The foot, like the hand, is divisible into three regions : the *tarsus* or ankle, the *metatarsus* or mid-foot, and the *phalanges* or toe-bones. The tarsus, like the carpus, consists of two rows, but with only two bones in each. Those of the proximal row (*astragalus* and *calcaneum*) are greatly elongated (Fig. 9, AST., CAL.), and furnish an additional segment to the limb, thus increasing the frog's leaping powers : those of the distal row are very small.

The metatarsals are five in number : those of the first and second digits (I, II) bear two phalanges each, those of the third and fifth, three each, and that of the fourth, four. Attached to the inner side of the tarsus is a little claw-like structure (C) composed of two or three bones and called the *calcar* or spur.



Notice the striking correspondence in structure between the fore- and hind-limbs, a correspondence which extends also, though less obviously, to the limb-girdles. The humerus corresponds or is serially homologous (p. 34) with the femur, the radius with the tibia, the ulna with the fibula, the carpals with the tarsals, the metacarpals with the metatarsals, and the phalanges of the fingers with those of the toes. Then in the limb-girdles the glenoid cavity corresponds with the acetabulum, the scapula and supra-scapula (being above the articular cavity) with the ilium, the precoracoid and clavicle (being ventral and anterior in position) with the pubis, and the coracoid with the ischium. Thus not only are the limbs and limb-girdles serially homologous structures, but their several parts are also serially homologous, each to each.

Nature of Bone.—It is a mistake to suppose that bones are made exclusively of hard mineral matter, like rocks or stones. If one of the long bones, for example, is put into weak acid, bubbles of gas will rise from the bone, showing that the carbonate of lime, of which it is partly composed, is being decomposed with the liberation of carbon dioxide. When the liberation of bubbles is over, the bone will be found to be unaltered in form, but to be quite flexible instead of hard and rigid. It can be bent in any direction, and a bone of sufficient length, such as a sheep's rib, can be tied in a knot. This shows that the bone contains a large amount of organic or animal matter. On the other hand, a bone may be completely *calcined* by heating to redness in a closed vessel, when its animal matter is completely consumed and its mineral matter left. Under these circumstances it becomes very brittle, falling to pieces at a touch, and its appearance is far more altered than by the removal of the mineral matter.

CHAPTER IV

THE FROG (*continued*): THE JOINTS AND MUSCLES

In the previous chapter the bones—more than 150 in number—which together constitute the greater part of the skeleton of a frog have been considered as so many separate parts, fitting into or against one another in certain ways. We must now see how they are joined together in the entire animal so as to afford the requisite support, and, at the same time, to allow of free movement.

The Hip-joint.—Let us begin by a study of the hip-joint (Fig. 18).

The acetabulum (*actb*), as you have already seen (p. 49), is a hemispherical depression on the outer surface of the hip-girdle. It is formed of cartilage, continued into a projecting rim round the edge of the cavity. The head of the femur (*hd*) is also formed of cartilage, and fits accurately but rather loosely in the acetabulum.

The acetabulum is lined, and the head of the femur is covered, by a thin layer of connective-tissue, the *perichondrium* (*p. chd*), which, in both cases, is continued on to the adjacent bone, where it receives the name of *periosteum* (*p. ost*).

Attached all round the rim of the acetabulum is a strong sheet of connective-tissue called the *capsular ligament* (*cps. lg*), forming a short, fibrous tube. The other

end of this tube is fixed to the femur, just below the head, the ligament being continuous, in each case, with the perichondrium. There is thus a space between the head of the thigh-bone and the acetabulum, closed all round by the capsular ligament. This space is filled with a delicate, fibrous, closed bag, the *synovial capsule* (*sy. cps*), one side of which fits closely into the acetabulum, while the other as closely invests the head of the femur.

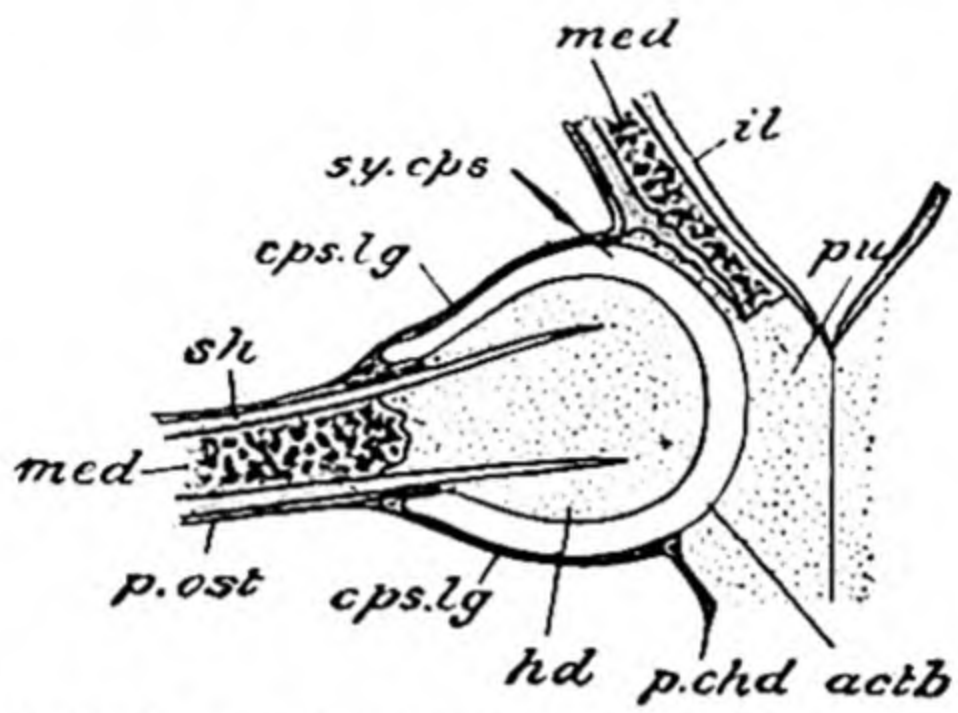


FIG. 18.—Horizontal section of a Frog's hip-joint. (× 5.)
actb. acetabulum; *cps. lg.* capsular ligament; *hd.* head of femur; *il.* ilium; *med.* marrow; *p. chd.* perichondrium; *p. ost.* periosteum; *pu.* pubis; *sh.* shaft of femur; *sy. cps.* synovial capsule.

The capsule is filled with a watery fluid, the *synovia*, and thus forms a buffer or water-cushion between the adjacent parts of the skeleton. Thus the synovial capsule keeps the two parts slightly apart and prevents friction, while the capsular ligament keeps them together and prevents dislocation.

It is obvious that, in such a joint as this, movement is possible in all directions. The femur can be inclined either upwards, downwards, or sideways, and is capable of a certain amount of rotation. The joint is, in fact, a *cup-and-ball joint*, and is capable of movement in any plane. A similar but less perfect cup-and-ball joint is

that of the shoulder, in which the cup is furnished by the glenoid cavity, the ball by the head of the humerus.

Other Joints.—The elbow- and knee-joints are constructed on the same general plan, but, owing partly to the form of the adjacent surfaces, partly to the mode of attachment of the ligaments, they are capable of movement in one plane only, *i.e.*, up and down, but not from side to side. They are therefore distinguished as *hinge-joints*.

The vertebræ are connected with one another in a similar way. Between the convex hinder face of one centrum and the concave front face of its successor is a synovial capsule, and the two centra are bound together by ligament, a shallow cup-and-ball joint, with a very limited range of movement, being produced. There are also synovial capsules between the articular processes, which, being in contact with one another by flat surfaces and working mainly from side to side, form *gliding-joints*. Strong ligaments connect the neural arches with one another and join the first vertebra to the skull.

In all cases where free movement is necessary the joints are formed in the same way; the bones are bound together by ligaments, and a synovial capsule is interposed between their adjacent cartilage-covered surfaces. Where little or no movement is required, as between the bones of the shoulder- and hip-girdles, the union is effected by cartilage or ligament only, and there is no synovial capsule. Such joints are therefore distinguished as *immovable* or *imperfect joints*.

The Muscles.—We see then that the bones of the skeleton are attached to or articulated with one another by means of ligaments, so arranged, in most cases, as to allow of more or less free movement between the bones.

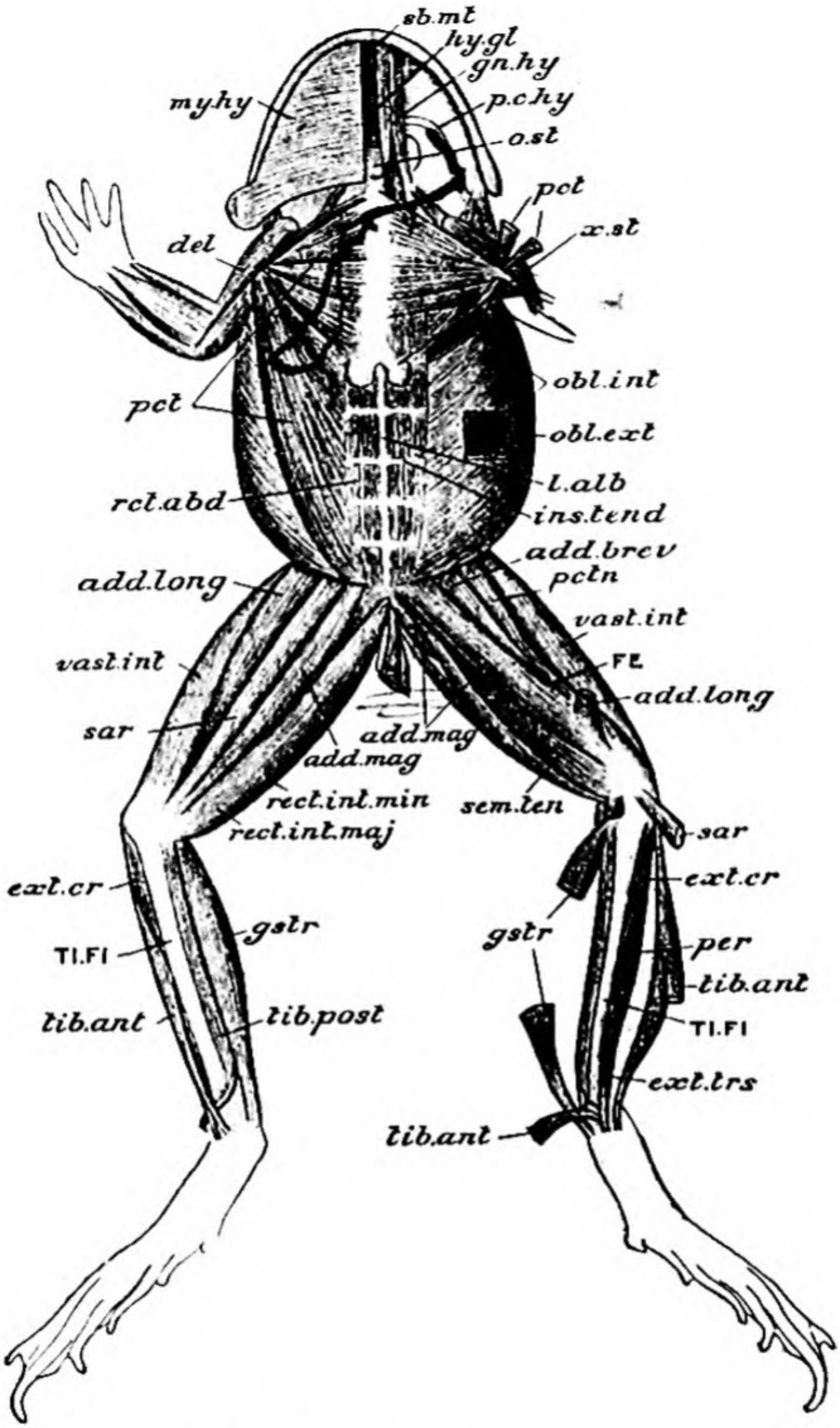


FIG. 19.—The muscles of a Frog from the ventral aspect. On the left side (right of figure) many of the superficial muscles have been cut and reflected to show the deep layer. (Natural size.)

add. brev. adductor brevis; *add. long.* adductor longus; *add. mag.* adductor magnus; *del.* deltoid; *ext. cr.* extensor cruris; *ext. trs.* extensor tarsi; FE. femur;

gn. hy. genio-hyoid; *gstr.* gastrocnemius; *hy. gl.* hyoglossus; *ins. ten.* tendinous inscription; *l. alb.* linea alba; *my. hy.* mylo-hyoid; *obl. int.* obliquus internus; *obl. ext.* obliquus externus; *o. st.* omosternum; *p. c. hy.* posterior horn of hyoid; *pct.* pectoralis; *pctn.* pectineus; *per.* peronæus; *rct. abd.* rectus abdominis; *rect. int. maj.* rectus internus major; *rect. int. min.* rectus internus minor; *sar.* sartorius; *sb. mt.* submentalis; *sem. ten.* semitendinosus; *tib. ant.* tibialis anticus; *tib. post.* tibialis posticus; TI. FI. tibio-fibula; *vast. int.* vastus internus; *x. st.* xiphisternum. (From Parker and Haswell's *Zoology*.)

We must now try to find out how the movements are effected in the living frog.

It was pointed out in the second chapter that the flesh is made up of distinct bands or sheets, the *muscles*, some of which came under your notice in your first dissection. It is quite easy to convince yourself that the whole of the flesh has this character by skinning a frog and carefully removing the fascia (p. 16) which covers the muscles and the more delicate web of connective-tissue which forms a sort of packing substance between them. After noticing some of the muscles shown in Fig. 19, especially those of the leg, give your attention to the muscle marked *gstr*, a prominent spindle-shaped mass of flesh forming the calf of the leg, and known as the *gastrocnemius* (*gstr*).

The spindle-shaped, fleshy mass or *belly* of this muscle is continued at either end into a band of strong, tough connective-tissue, the *tendon* (Fig. 20). The tendon at the proximal end is flat, and is attached to the distal end of the femur and to the proximal end of the tibio-fibula, in each case becoming continuous with the periosteum of the bone. The tendon at the distal end has the form of a stout cord, and is distinguished as the *tendo Achillis*; it corresponds with the strong tendon just above the heel of the human foot. At its distal end it is continued into a broad sheet of connective-tissue, the *plantar fascia*, which spreads over the whole sole or plantar surface of the foot.

If the foot is bent upon the shank as in the ordinary sitting position of the frog, and the gastrocnemius pulled

upwards or towards the thigh, the foot will instantly be bent backwards, so as to come into a straight line with the shank, the action being one of those performed by the living frog when leaping. It will be seen that the proximal tendon is attached to a relatively fixed point: it is distinguished as the tendon of *origin*, or the muscle is said to *arise* from the femur and tibio-fibula. The distal tendon is attached to a relatively movable part, the foot, and is called the tendon of *insertion*, the muscle being said to be *inserted* into the plantar fascia.

Muscular Contraction.—Obviously, however, there is nothing to pull upon the muscle from outside in the living frog. We must, therefore, try to form some idea as to how the action of bending the foot, roughly imitated in the dead subject, is performed during life. If the gastrocnemius be exposed in a recently killed frog, the foot bent up as before, and a smart pinch be given to the belly of the gastrocnemius, the foot will be bent back, although no pull has been exerted on the muscle. The same thing will happen if you drop on the gastrocnemius a single drop of weak acid or of a strong solution of common salt, or if you touch it with a hot wire, or if you apply to it the electrodes from an induction coil so as to pass an electric current through it.

Careful observation shows that what happens in either of these circumstances is that the belly of the muscle decreases in length and at the same time increases in breadth, so as to become shorter and thicker (Fig. 20). The result of this must necessarily be to cause its two ends to approach one another. As the tendon of origin is attached to the femur, which we suppose to be fixed, it is unable to move, and the insertion is therefore drawn upwards, bringing with it the movably articulated foot. In fact exactly the same thing takes

place as when we raise our own fore-arm. This action is performed by means of the biceps muscle which arises from the scapula and is inserted into the fore-arm. When the latter is raised we feel a lump rise on the front of the upper arm due to the thickening of the biceps.

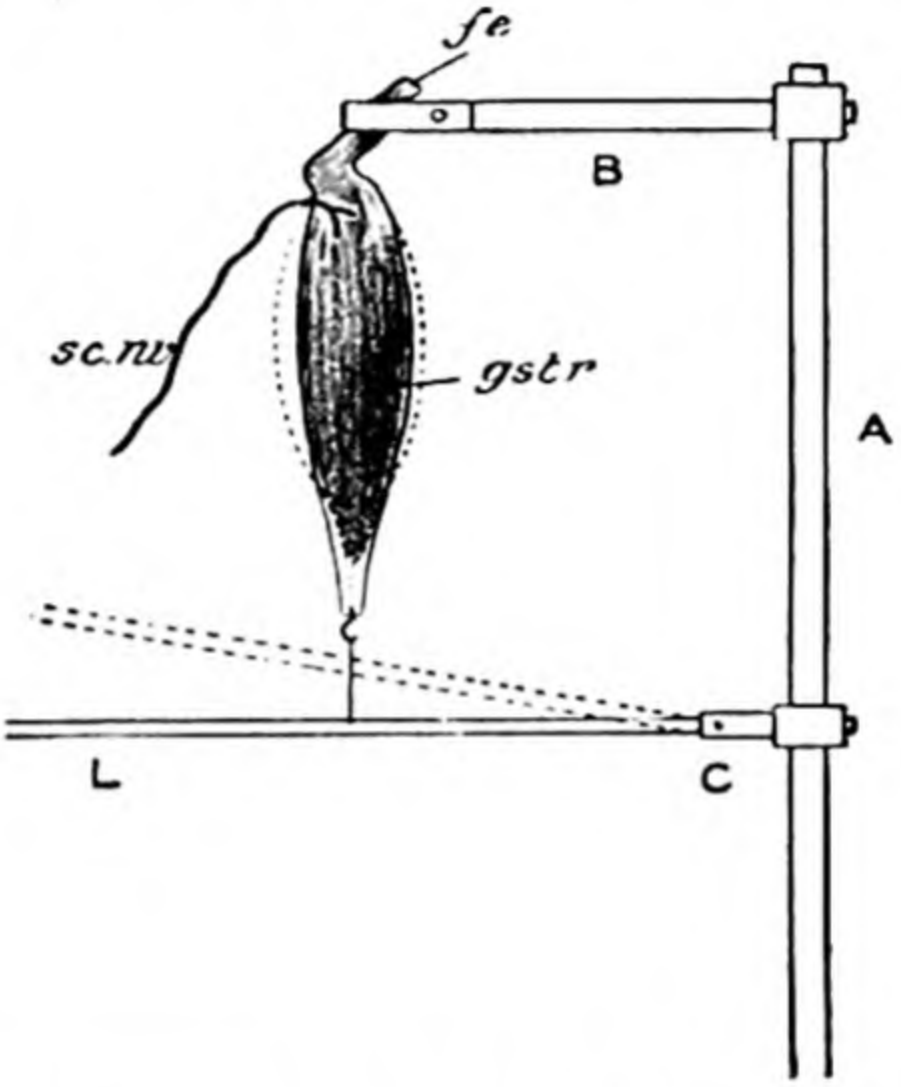


FIG. 20.—Diagram of apparatus for demonstrating the contraction of the gastrocnemius muscle.

A, upright, bearing two adjustable horizontal arms. To the upper of these (B) is fixed by a clamp the femur (*fe*), having the gastrocnemius (*gstr*) in connection with it. To the lower arm (C) is fixed a light lever (L) movable in a vertical plane, and having the tendon of insertion of the muscle attached to it by a thread. The dotted lines show the form of the gastrocnemius and the position of the lever during contraction of the muscle. *sc. nv.* the sciatic nerve.

This shortening and thickening of the muscle is termed a *contraction*. Do not fail to notice that this word is used in a special sense. When we say that a red-hot bar of iron contracts on cooling, we mean that it becomes smaller in all dimensions—undergoes an actual decrease in bulk. But in muscular contraction there is no alteration in bulk: the decrease in length is

balanced by an increase in thickness, as when a stretched piece of india-rubber is relaxed.

The external influence by which a contraction is induced is called a *stimulus*. As we have seen, a stimulus may be produced by actual contact of some external object (*mechanical stimulus*), or by chemical action (*chemical stimulus*), or by heat (*thermal stimulus*), or by an electrical current (*electrical stimulus*).

Relation of Muscle and Nerve.—Evidently, however, we have by no means got to the bottom of the matter. In the living frog movements are always going on, and all are due to the contraction of muscles, and yet no stimuli of the kind enumerated are applied to any of them. As the muscles retain the power of contraction for some little time after the death of the animal, it is easy to make such experiments as that described in the next paragraph.

Running longitudinally between the muscles on the dorsal side of the thigh is a shining, white cord, the *sciatic nerve* (Fig. 20, *sc. nv*), accompanied by an artery: it gives off branches to the muscles and skin, and, amongst others, one to the gastrocnemius. If, when quite fresh, this nerve be carefully separated as it traverses the thigh and pinched with the forceps, the gastrocnemius will contract just as if the stimulus had been applied to it directly, and the same will happen if a chemical, thermal, or electrical stimulus be applied.

Thus a stimulus applied to the nerve of a muscle has the same effect as if applied to the muscle directly: it gives rise to a *nervous impulse*, which, travelling along the nerve, induces contraction of the muscle.

Once more, however, external stimuli are not applied to the frog's nerves during life, and it is obvious that we must carry our inquiry a little further. The sciatic nerve if traced upwards will be found to pass into the

trunk (Fig. 53, *sci*), and finally to join the spinal cord, which, as we have seen, is in connection with the brain. In the living frog nervous impulses originate in the brain, without the direct intervention of an external stimulus, and are conducted along the cord and nerves to the muscles. But further consideration of this subject must be deferred until we have made a special study of the nervous system.

The Muscular System in General.—All over the body the muscles, though varying greatly in form—some being elongated and band-like (Fig. 19, *sar*), others spindle-shaped (*gastr*), others in the form of broad, flat sheets (*my. hy, obl. ext*)—have the same general relation to the skeleton as in the case of the gastrocnemius. Each muscle arises or has its origin in a relatively fixed part, and is inserted into a relatively movable part. As each muscle contracts in one direction only, it follows that the more complex the movements any part is capable of performing, the more numerous must be its muscles. For instance, the femur, which, as we have seen, is capable of universal movement, has no fewer than nine muscles, arising from various parts of the hip-girdle, inserted into it. Even the minute phalanges of the fingers and toes all have their little slips of muscle by which the various movements of grasping and relaxing, approximating and separating the digits, are effected.

There are certain terms applied to muscles which it is useful to know. A muscle which raises a part, *e.g.*, the lower jaw, is called a *levator*, one which lowers a part a *depressor*. A muscle which serves to straighten one part upon another, *e.g.*, to bring the shank into line with the thigh, is an *extensor*, one which bends one part on another is a *flexor*. A muscle which draws, *e.g.*, a limb towards the trunk is an *adductor*, one which draws it away an *abductor*, one which rotates one part upon another (*e.g.*, the femur on the pelvis), a *rotator*.

Thus all the complex and accurately adjusted movements of the frog are performed by the contraction of its numerous muscles, acting either singly or in concert. The contractions of these muscles are brought about by nervous impulses sent from the brain or spinal cord along nerves which branch out and are distributed to the muscles, thus bringing the whole of the complex machinery which affects the movements of the animal under the direct control of its will.

CHAPTER V

THE FROG (*continued*) : WASTE AND REPAIR OF SUBSTANCE —THE DIGESTIVE ORGANS—NUTRITION

Waste and Repair.—The effects of prolonged muscular exertion are familiar to everyone. Sooner or later sensations of fatigue, hunger, and thirst are produced, accompanied by a loss of weight. Indeed, however little exertion we make and however often we feed, our weight always goes down between meals and rises again when we take food. The loss of substance, of which the diminution in weight is the index, takes place largely in the form of perspiration, a fluid consisting of water with certain organic and inorganic matters in solution. A further loss is due to the air breathed out from the lungs; this is always moist, *i.e.*, contains a good deal of water, and is further distinguished by containing a considerable volume of carbonic acid gas or *carbon dioxide* (CO_2). Besides these two constant sources of loss, there is an intermittent loss in the urine, which consists of water containing certain matters in solution, the most characteristic of which are two complex substances called urea (CON_2H_4) and uric acid ($C_5H_4N_4O_3$). Both of these, as well as carbon dioxide, act as poisons if allowed to remain in the system. Lastly there is an intermittent source of loss in the waste matters or fæces which are passed out from the intestine.

These losses are made good in two ways. Firstly, by breathing, in which process we constantly inhale pure air and replace the poisonous carbon dioxide by oxygen. Secondly, by eating and drinking, by which, at intervals, we make good the loss of solids and liquids. Just as a clock is constantly running down and has to be wound up in order to keep it going, so our bodies run down by loss of substance between meals, and require to be wound up by the repair of substance which results from food and drink.

The same thing is true of the frog. Every one of its numerous and often vigorous movements is done at the expense of a certain waste of substance. The various tissues of the body are constantly undergoing a process of wear and tear, expressed not as in machines of human construction, by a wearing away of surfaces and a loosening of bolts and screws, but by a slow and almost imperceptible dwindling, the lost material being carried off principally in the form of water, carbon dioxide, and urea or some allied compound containing nitrogen.

Food of the Frog : General Characteristics of the Digestive Process.—As we have seen, the food of the frog consists of worms, slugs, insects, and the like. These it catches and swallows whole, the stomach often becoming immensely distended with numbers of captured animals. After remaining for some time in the stomach the carcases are found to have undergone a marked change. Their soft parts become softer and slimy and finally semi-fluid, and in this way the food undergoes gradual disintegration. The quantity of food in the stomach decreases, some of it is passed into the intestine, which it traverses from duodenum to rectum, and certain portions of it are finally ejected from the vent in the form of fæces.

It is not difficult to assure oneself that the weight of the fæces passed during a certain time is very much less than that of the food swallowed during the same time. Obviously some constituents of the food have disappeared during its progress through the alimentary canal. The character of the fæcal matter, moreover, is very different from that of the food; the only portions of the swallowed animals discoverable in the rectum are bits of their hard parts; for the rest, the fæces form a pulpy, black mass. That this change is due to certain definite chemical processes taking place in the alimentary canal may be inferred from the fact that the contents of the stomach, as well as the walls of that organ, have an acid reaction, and turn blue litmus paper red. On the other hand, the contents of the small intestine are, to a greater or less extent, alkaline, restoring reddened litmus paper to its original blue colour.

It is also obvious that there must be some definite mechanism for propelling the food from one end of the alimentary canal to the other; its passage through so long, narrow, and coiled a tube can certainly not be accounted for by supposing it to be merely pushed onwards as fresh food is swallowed.

In order to understand the various processes connected with digestion we must make a renewed and more careful examination of the organs concerned.

The Digestive Organs.—By cutting open the alimentary canal and examining its inner surface under water with a magnifying glass, it is seen that the wall of the canal consists of two layers, easily separable from one another. The outer or *muscular layer* (Fig. 22, A, *musc*), covered by the peritoneum (p. 24), is tough and strong, the inner layer or *mucous membrane* (*m.m.*) is soft and slimy. Between the two is very loose connective-tissue, the *submucosa*, which, being easily torn, allows of

the ready separation of the muscular and mucous layers.

In the stomach the mucous membrane is raised into

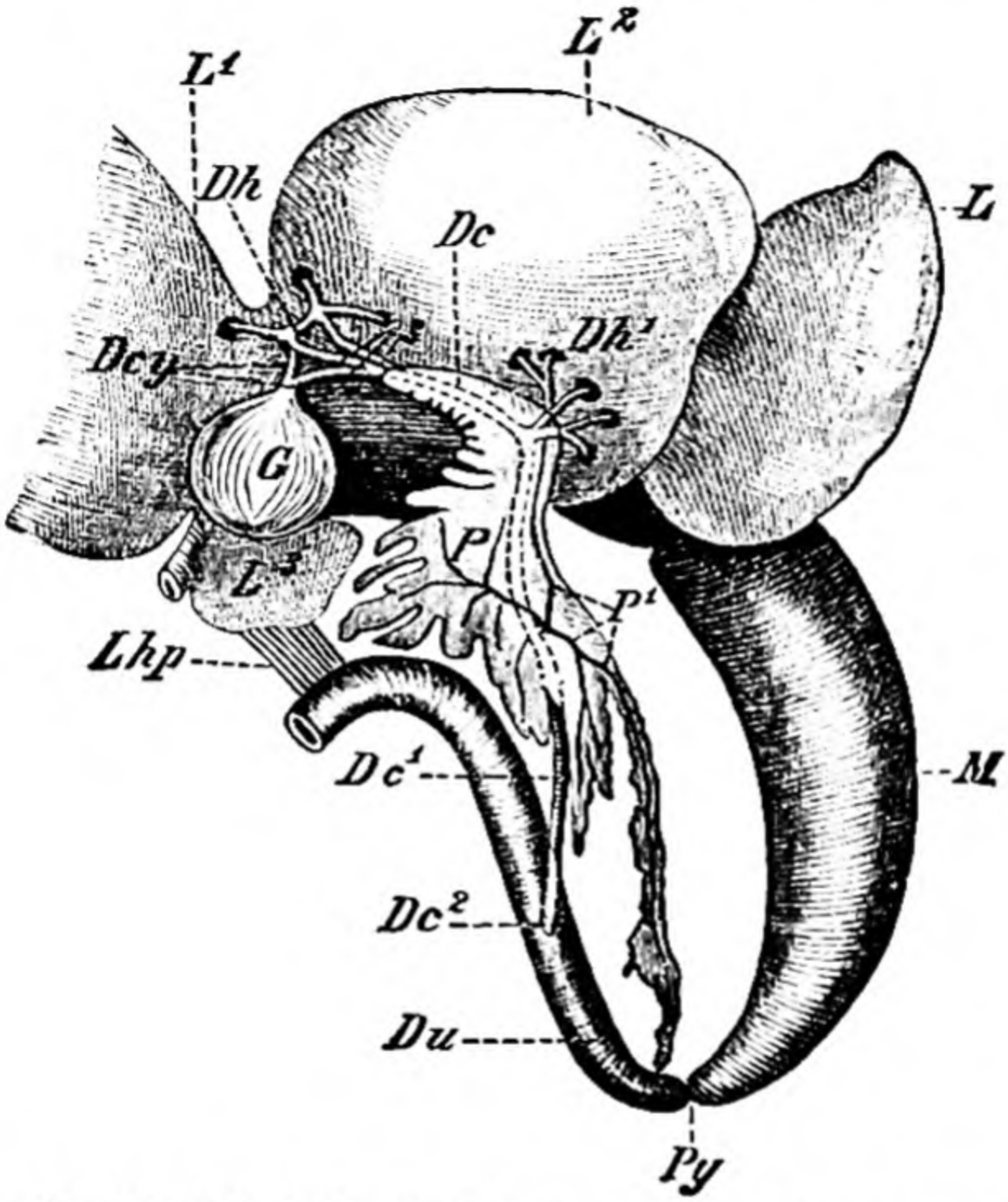


FIG. 21.—Stomach and duodenum of *Rana esculenta*, with liver and pancreas. (× 2½.) *Dc*, *Dc.*¹ common bile-duct; *Dc.*² its opening into the duodenum; *D. cy.* cystic ducts; *Dh*, *Dh.*¹ hepatic ducts; *Du.* duodenum; *G.* gall-bladder; *L*, *L*¹, *L*², *L*³, lobes of liver, turned forwards; *Lhp.* duodeno-hepatic omentum, a sheet of peritoneum connecting the liver with the duodenum; *M.* stomach; *P.* pancreas; *P*¹, pancreatic duct; *Py.* pylorus. (From Wiedersheim's *Comparative Anatomy.*)

longitudinal folds (Fig. 22, *A*, *r*), in order to allow of distension; in an empty stomach these are well marked, and give the cavity a star-like cross-section (Fig. 43); in one full of food they are entirely obliterated and the

walls of the organ so stretched as to be almost transparent. Anteriorly the ridges thin out and disappear at the *cardia* or junction between the gullet and stomach; posteriorly they converge, as the stomach narrows, towards the *pylorus* (Fig. 22, A, *py*), or junction with the duodenum. Here the muscular coat is greatly

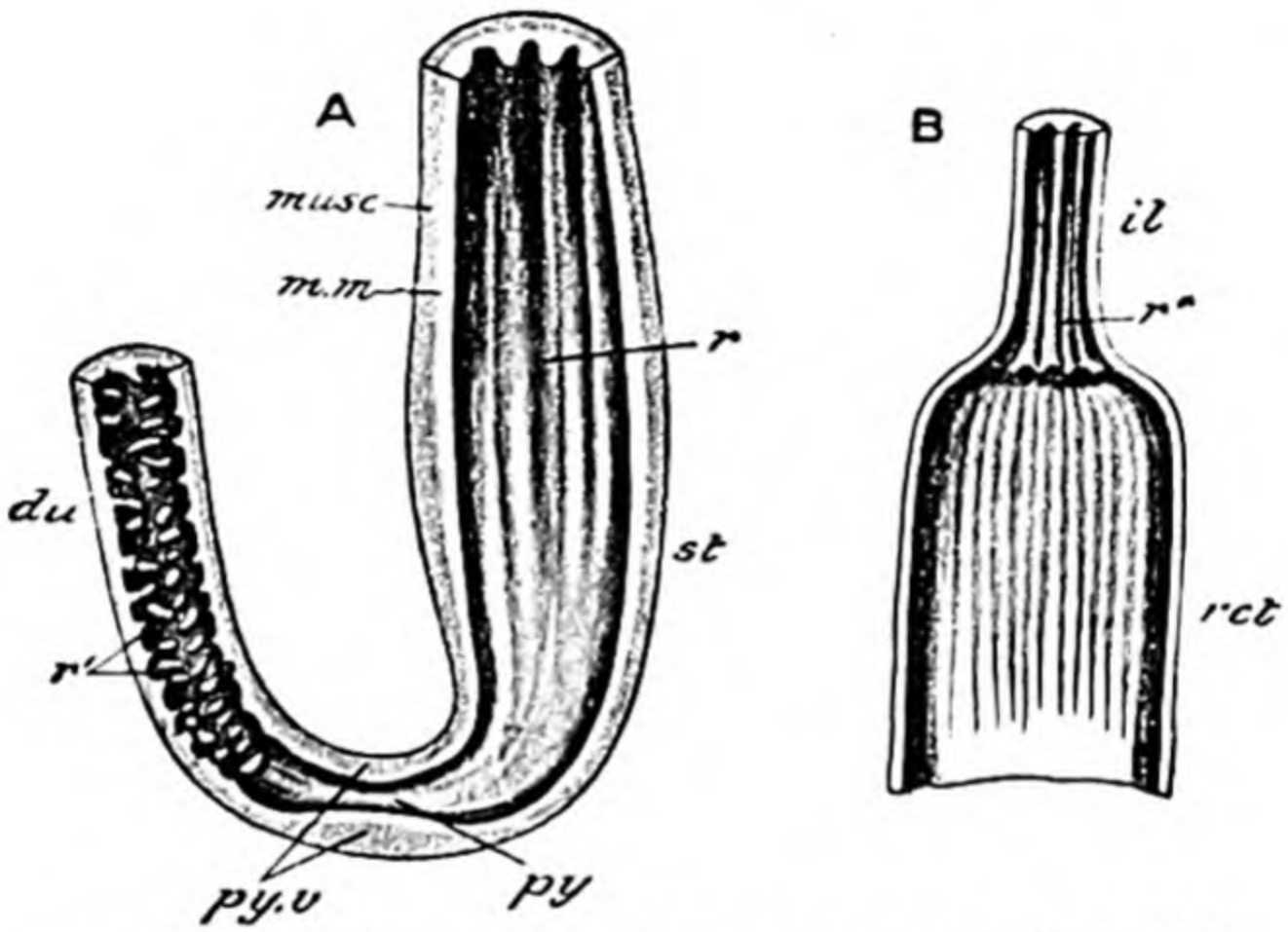


FIG. 22.—Portions of the alimentary canal of a Frog in longitudinal section. (× 3.) A, stomach and duodenum; B, part of ileum and rectum; *du.* duodenum; *il.* ileum; *m. m.* mucous membrane; *musc.* muscular layer; *py.* pylorus; *py. v.* pyloric valve; *r.* longitudinal ridges (rugæ) of stomach; *r'.* transverse ridges of duodenum; *r''.* longitudinal ridges of ileum; *rct.* rectum; *st.* stomach.

thickened in a ring-like form, forming the *pyloric valve* (*py. v*), by which the aperture of communication between the stomach and intestine is greatly narrowed, so that only small particles can pass through. In the duodenum (*du*) the mucous membrane is raised into little tuft-like elevations (*r'*); in the ileum the ridges (B, *r''*) become longitudinal again; in the rectum (*rct*) they are absent. Another ring-like muscle, or *sphincter*, is present round the vent.

When food is taken into the stomach, a fluid, the *gastric juice*, oozes from the mucous membrane. It is this fluid which reduces the slugs, insects, etc., to the pulpy condition referred to above: it is, like the bile and pancreatic fluid, a digestive juice.

Arising from the gall-bladder and passing backwards to the duodenum is an extremely delicate tube (Fig. 21, *Dc*, *Dc*^{1}), the *common bile-duct*, which opens into the duodenum. By gently squeezing the gall-bladder a drop of greenish fluid may be made to ooze out of the end of the duct (*Dc*^{2}) into the intestine; this fluid is the *bile*.

Very careful dissection shows that the common bile-duct is joined by several other tubes which are traceable into the liver and are called *hepatic ducts* (*Dh*, *Dh*^{1}). The tubes going to the gall-bladder are called *cystic ducts* (*D.cy*); by their union with the hepatic ducts the common bile-duct is formed.

The bile is manufactured in the liver, and the gall-bladder is merely a reservoir in which it is stored up, to be discharged into the intestine when required for digestion.

It requires still more accurate observation to show that the pancreas also discharges a fluid, the *pancreatic juice*, into the intestine. A very delicate branching tube, the *pancreatic duct* (*P*^{1}), joins the bile-duct, into which it discharges the pancreatic juice, the two fluids entering the intestine together. Both fluids are *digestive juices*, *i.e.*, liquids which, as we shall see, act in a particular way upon the food.

General Properties of Food.—We must now devote a little attention to the characters of the food itself and to the precise nature of the changes brought about by the digestive process.

As we have seen, the frog is a carnivorous animal.

Now, the digestible part of the substance of animals consists mainly of two classes of chemical compounds, called *proteins* and *fats*. The most familiar example of a protein is white of egg : other proteins, of varying composition, are found in muscle, in blood, and in other animal tissues. All are composed of the five chemical elements—carbon, hydrogen, oxygen, nitrogen, and sulphur—the five elements being combined in the following proportions :—

Carbon .	.	from 51·5	to 54·5	per cent.
Hydrogen	.	,, 6·9	,, 7·3	,,
Oxygen .	.	,, 20·9	,, 23·5	,,
Nitrogen	.	,, 15·2	,, 17·0	,,
Sulphur .	.	,, 0·3	,, 2·0	,,

Fats differ from proteins in containing no nitrogen or sulphur : they are formed of carbon, oxygen, and hydrogen, the number of atoms of hydrogen being typically more than twice as great as the number of atoms of oxygen.

It will be noticed that two important articles of diet are absent from the above list, namely *sugar* and *starch* —the latter the largest constituent of flour, oatmeal, rice, etc. The vegetable substances, such as corn and grass, used as food by animals, contain these bodies in varying proportions in addition to vegetable proteins, and there is no doubt that the frog must eat a small quantity of such vegetable food, if only in the stomachs of the herbivorous animals upon which it preys. Now, starch and sugar belong to a group of compounds called *carbohydrates*, composed of carbon, oxygen, and hydrogen, but differing from fats in that the number of atoms of hydrogen is always exactly double that of the atoms of oxygen, as in water. Lastly, the food always contains a certain quantity of salts or mineral

matters, vitamins and water. Vitamins are substances, minute quantities of which are essential for proper growth and for maintaining the body in a healthy condition.

Diffusible and Non-diffusible Foods.—These four classes of food materials—proteins, fats, carbohydrates, and minerals—may be arranged in two groups according to a certain physical peculiarity. If a solution of common salt is placed in a vessel with a bottom made of bladder, called a *dialyser*, which is floated in a larger vessel of pure water, it is found that, after a certain lapse of time, the water in the outer vessel has become salt. The sodium chloride has, in fact, passed by *diffusion* or *osmosis* through the bladder. The same thing will happen if a solution of sugar is placed in the inner vessel: salt and sugar are both *diffusible* substances, capable of passing through an animal membrane.

On the other hand, if the inner vessel contains white of egg, or oil, or starch well boiled in water, no diffusion takes place. Hence proteins, fats, and starch are *non-diffusible* foods, and are thus sharply distinguished from salt and sugar, which are diffusible.

The mucous membrane of the stomach and intestine are animal membranes having the same physical properties as bladder. We may consequently infer that any salt or sugar contained in the alimentary canal will diffuse through the mucous membrane and make its way, as we shall see more particularly hereafter, into the blood, thus serving to nourish the whole body. Proteins, fats, and starch, on the other hand, will be incapable of diffusing, and will, therefore, unless some change happens to them, be absolutely useless as nutriment. For, since the alimentary canal communicates with the outer world at both ends, the food, paradoxical as it may sound, is practically outside the body as long as it remains in the canal: it is only when it is absorbed into the blood or lymph that

it is actually, in the strict sense, taken into the body. Thus if proteins, fats, and starch are to be of any use to the frog, they must, in some way, be rendered capable of being absorbed, in which process the living tissues appear to exercise some degree of selection.

Action of Digestive Juices.—This is exactly what is done by the digestive juices. If white of egg or any other protein is mixed with gastric juice and kept at a suitable temperature, it is converted into a form of protein called *peptone*, which is capable of diffusing through an animal membrane. The change is effected by means of a substance called *pepsin*, contained in the gastric juice in which there is also a certain proportion of hydrochloric acid. To this the acid reaction of the gastric juice already alluded to (p. 67) is due.

By means of the gastric juice the bodies of the animals swallowed by the frog have their proteins largely converted into peptones, which, being diffusible, pass through the mucous membrane as readily as sugar or salt. Hence the great diminution in the bulk of the food during its sojourn in the stomach : a large proportion of it is absorbed there and then, and only a comparatively small quantity is passed through the pyloric valve into the intestine, where it becomes alkaline, owing to the action of the fluid which enters the duodenum through the bile-duct, and which, as we have seen (p. 67), consists of bile and pancreatic juice.

Pancreatic juice has a similar effect on proteins, the change being effected by a substance called *trypsin*, which, however, acts in an alkaline solution. It also has the property of converting starch into sugar, and of splitting up fats into fatty acids and glycerine, both of which are diffusible. The substances by which these changes are effected are called by the general name of *ferments* : pepsin and trypsin are protein-converting

ferments, and the pancreatic juice also contains a ferment which converts starch into sugar, and a fat-splitting ferment.

The exact mode of absorption of the fats is not thoroughly understood. It is usually supposed that only a small proportion of them are decomposed into fatty acids and glycerine, and that the greater part is merely broken up into particles so small that they can be taken up by the epithelial cells of the intestine. This *emulsification* of fat is effected by the combined action of the pancreatic juice and bile, the fats being reduced to the condition in which they exist in milk and in the emulsions of cod-liver oil so much used in place of the natural form of that medicine.

Thus during the passage of the food through the intestine the remainder of the proteins, the whole of the fats, and any starch which may be present, are rendered capable of being absorbed: they pass through the mucous membrane into the blood, and by the time the rectum is reached all the nutriment is extracted from the food, and there remains only a small quantity of indigestible matter which is passed out in the form of fæces.

In man and other mammals the process of digestion begins in the mouth-cavity. The food is divided into fine particles by the teeth and mixed with a secretion called saliva, which is produced in certain glands and poured into the mouth cavity by certain ducts. The saliva is, like the pancreatic juice, alkaline in reaction, and contains a ferment called *ptyalin*, which is capable of converting starch into sugar. There are no salivary glands in frogs, and the teeth also are not for the purpose of masticating the food, but for preventing the prey from slipping out of the mouth.

Most of our knowledge of the processes of digestion is derived from experiments on man and other animals. In the course of these it has been established that the mucous membrane of the small intestine also fulfils important functions in the process of digestion. When pancreatic juice is first formed, and indeed before it reaches the small

intestine, it is unable to act upon proteins. This is because trypsin is only made active and able to do its work when it meets a peculiar substance called *entero-kinase* formed by the wall of the small intestine. Besides this, certain other ferments are also formed by the tubular glands of the intestine in a small amount of the intestinal juice. One of these changes the malt-sugar formed from starchy food and another changes cane-sugar partly into grape-sugar and partly into another sugar like it, called fruit-sugar. Yet another ferment, called *erepsin*, changes peptones into still more soluble substances, called *amino-acids*. The chief function of the mucous membrane of the small intestine, however, is to absorb the digested food. This is carried out by the villi (Fig. 23). The epithelial cells covering the villi have the power of taking up, from the fluid in the cavity of the intestine, peptones, and amino-acids formed from them, sugar, salts, and water, as also finely divided fat. They have also the power of passing these substances on to the blood-vessels and lymphatics, although some of these substances become more or less altered during absorption, *e.g.*, peptones which are changed into amino-acids, sugar, most of the salts, and a great deal of water pass into the blood-capillaries in the substance of the villi, and are carried by the portal vein to the liver. On the other hand, the dissolved fat taken up by the epithelial cells passes into the lacteals and is carried away along the lymphatics, and ultimately reaches into the blood of certain veins into which the lymphatics finally open.

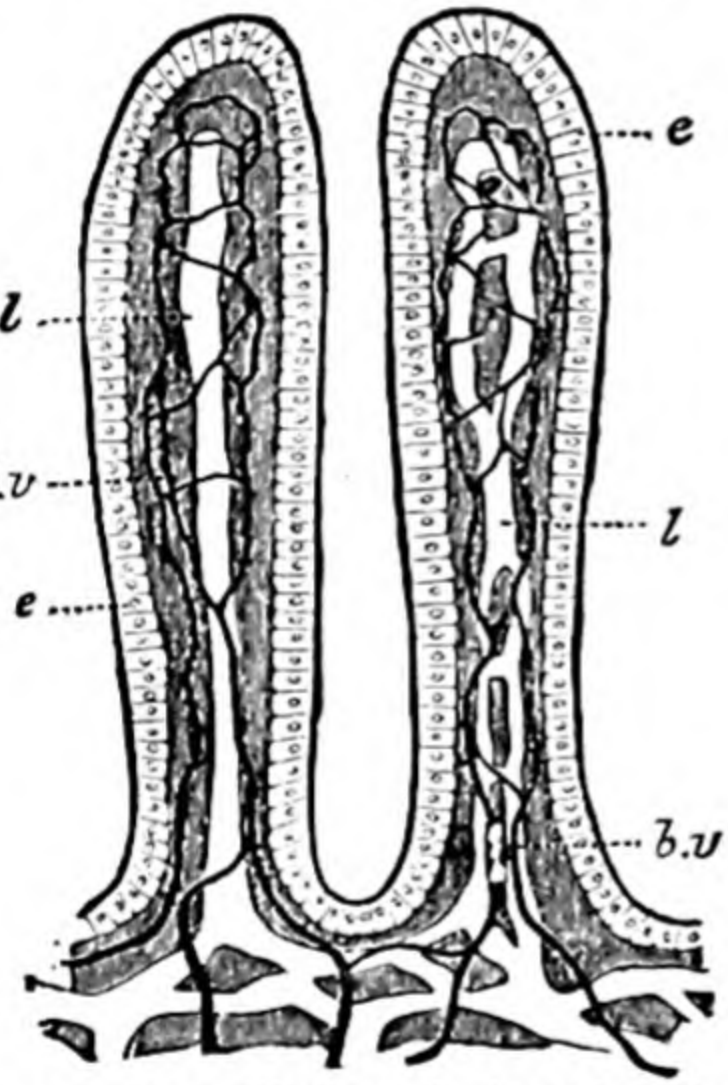


FIG. 23.—Two villi from the intestine of a mammal, highly magnified.
e. layer of epithelial cells; *b. v.* blood-vessels; *l*. lacteals. (From Foster and Shore's *Physiology*.)

Peristaltic Movements.—The passage of the food through the alimentary canal is effected by the contrac-

tion of its muscular layer, which is really double, and which is composed of *muscular fibres* (*see* p. 117, and Figs. 42 and 43). In the inner layer these fibres have a transverse direction, encircling the tube, and by their contraction narrowing it; the outer layer consists of longitudinal fibres, which by their contraction shorten it. By the alternate contraction and relaxation of the two layers are produced a series of *peristaltic movements*, not unlike those by which an earthworm makes it way over the ground: they can be seen in a freshly-killed frog, and still better in a rabbit or rat.

Summary of Chapter.—The body is constantly undergoing waste, and in consequence needs continual repair. The waste matters chiefly take the form of carbon dioxide, water, and urea. Repair is effected partly by breathing (*see* Chapter IX), partly by feeding. Food, consisting of proteins, fats, carbohydrates, inorganic substances, as well as water, is taken into the alimentary canal, where by the action of the three digestive juices—gastric juice, pancreatic juice, and bile—it is converted partly into a solution (peptones, sugar, fatty acids, glycerine), partly into an emulsion (fats). As it is driven along the canal, from stomach to rectum, by the action of the muscular coat, the dissolved or emulsified substances gradually disappear from the canal, and are absorbed into the system. Finally, the indigestible constituents are expelled as fæces.

Our next task must be to learn something of the process of absorption, and of the means by which the digested food is conveyed to the various parts of the body, so as to supply them with the means of repairing the waste they are constantly undergoing. For this purpose we must now study what is called the *vascular system*, *i.e.*, the heart, the blood-vessels, and the various cavities containing lymph.

CHAPTER VI

THE FROG (*continued*): THE VASCULAR SYSTEM—THE CIRCULATION OF THE BLOOD

In our preliminary examination of the frog (Chapter II) we learned one or two facts about the vascular system. We found that there is a heart within a pericardium, two sets of vessels, arteries and veins, containing red blood, and a set of irregular cavities or sinuses, containing lymph. We must now try to get some more accurate and detailed information on these matters.

General Characteristics of Blood and Lymph.—It will be convenient to begin by studying certain easily verified characteristics of the blood. Frog's blood may be used, or, as it is as well to have a considerable quantity, that of some larger, freshly-killed, red-blooded animal, such as a rat or rabbit.

When first drawn from the heart or vessels the blood will be seen to be a fluid, nearly as mobile as water or milk; it "finds its level," like any other liquid, and can be readily poured from one vessel to another. In a few minutes, however, it undergoes a change; it ceases to be fluid, and *coagulates*, or "sets" into a jelly, which, if turned out of the vessel, retains the shape of the latter. Before long a further change takes place; the jelly

begins to shrink, drops of yellowish fluid appear on its surface and gradually run together into larger and larger drops. The jelly contracts still further, and finally draws itself away from the walls of the vessel and floats in the accumulated fluid, still retaining the form of the vessel, but being greatly reduced in size. The process of coagulation of the blood is now complete; the red, jelly-like substance is called the *clot*, the yellowish fluid the *serum*.

When first drawn from most veins the blood is deep purple in colour, and the clot retains for a time the same hue. But before long all parts of it which are fully exposed to the air take on a bright scarlet colour. We may therefore distinguish between red, or *aërated*, and purple, or *non-aërated* blood.

Lymph also coagulates on standing, producing a colourless clot. It is practically blood *minus* its peculiar red colouring matter, the properties of which, as well as the real nature of coagulation, will be discussed in the next chapter.

The Heart : external characters.—Some of the divisions of the heart have already been noticed (p. 18). The *ventricle* (Figs. 4, 5, 8, 24, 25, and 26, *v*, *vt*) is a conical body of a pinkish colour, having its bluntly-pointed apex directed backwards. To its broad base is attached the dark-coloured, thin-walled *auricular division*, actually consisting of two chambers, the *right* and *left auricles* (*r. au*, *l. au*), but appearing single in the entire heart. Passing obliquely across the auricles is a cylindrical structure, the *truncus arteriosus* (*c. art*); it starts from the right side of the base of the ventricle, and passes forwards and to the left, finally dividing near the anterior boundary of the auricles into two branches, which extend respectively right and left.

By lifting up the ventricle, or turning it to one side

(Figs. 5 and 25), there is seen in the dorsal part of the pericardial cavity a thin-walled chamber (Fig. 25, *s. v*) of a dark colour, connected with the right side of the auricular division. This is the *sinus venosus*.

The Arteries.—The two branches of truncus arteriosus just referred to soon branch again. Each divides into three vessels, often spoken of as *arterial arches*, called respectively the *carotid trunk* (Fig. 24, *car. tr*), the *systemic trunk* (*syst. tr*), and the *pulmo-cutaneous trunk* (*pul. cu. tr*). All these conform to the definition of an artery given on p. 25, *i.e.*, they are stout, elastic vessels, containing little blood after death, and not collapsing when empty.

The carotid trunk divides immediately into two, a *lingual artery* (*lg*), which can be traced to the tongue, and a *carotid artery* (*car*), which branches repeatedly, its ultimate ramifications going to various parts of the head. At the origin of the carotid is a little rounded mass with a sponge-like interior, the *carotid labyrinth* (*car. gl*) formed by the artery breaking up into minute vessels which unite to form the artery again, which continues its onward course.

The systemic or aortic trunk extends outwards, in contact with the gullet, then sweeps upwards, backwards, and inwards—*i.e.*, towards the middle line—and finally joins with its fellow of the opposite side to form a single median vessel, the *dorsal aorta* (Figs. 5, 6, and 24, *d. ao*), which passes backwards just beneath the vertebral column and between the kidneys.

As it sweeps round the gullet, the systemic trunk gives off a *vertebral artery* (Fig. 24, *vert*) to the vertebral column and part of the head, a *subclavian artery* (*scl*), passing into the fore-limb as the *brachial*, and an *œsophageal artery* (*œs*) to the gullet.

From the point of union of the two aortic trunks

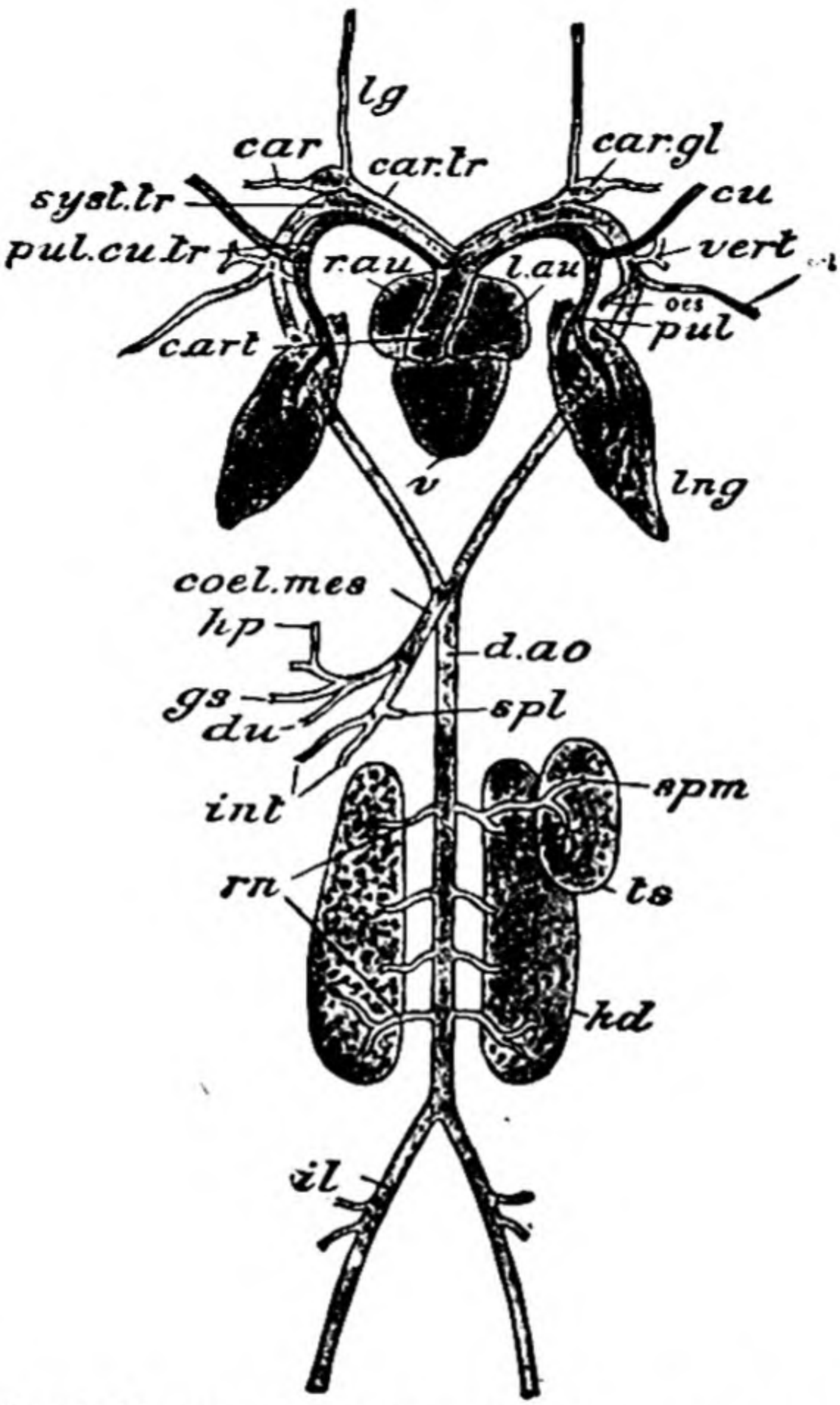


FIG. 24.—The arterial system of the Frog, with the heart, lungs, kidneys, and left spermary, supposed to be removed from the body and viewed from the ventra aspect. (× 2.)

car. carotid artery; *car. gl.* carotid labyrinth; *c. art.* truncus arteriosus; *car. tr.* carotid trunk; *cœl. mes.* cœliaco-mesenteric artery; *cu.* cutaneous artery; *d. ao.* dorsal aorta; *du.* duodenal artery; *gs.* gastric artery; *hp.* hepatic artery; *il.* iliac artery; *int.* intestinal arteries; *kd.* kidney; *l. au.* left auricle; *lg.* lingual artery; *lng.* lung; *œs.* œsophageal artery; *pul.* pulmonary artery; *pul. cu. tr.* pulmo-cutaneous trunk; *r. au.* right auricle; *rn.* renal arteries; *scl.* subclavian artery; *spl.* splenic artery; *syst. tr.* systemic trunk; *spm.* spermatic artery; *ts.* spermary; *v.* ventricle; *vert.* vertebral artery. (From Parker and Haswell's *Zoology*.)

springs a single *cœliaco-mesenteric artery* (*cœl. mes*); it divides into several branches, which are traceable to the liver (*hp*), stomach (*gs*), duodenum (*du*), spleen (*spl*), and ileum (*int*).

The dorsal aorta gives off on either side four *renal arteries* (*rn*) to the kidneys, and *spermatic arteries* (*spm*) in the male, or *ovarian* in the female, to the reproductive organs, and at the posterior end of the abdominal cavity divides into the right and left *iliac arteries* (*il*). Each iliac gives off a small *hypogastric* to the bladder, and then passes into the hind-limb as a *sciatic*. Just before the point of bifurcation of the aorta, a small *posterior mesenteric artery* is given off to the rectum.

The pulmo-cutaneous trunk divides into two main branches, the *pulmonary artery* (*pul*) which goes to the lung, and the *cutaneous artery* (*cu*) which forms an extensive system of branches over the skin.

With proper care all these arteries can be traced into the various organs to which they are distributed, when they will be found to branch repeatedly, sending ramifications to all parts. The iliac artery, for instance, may be followed along the whole length of the leg, giving off branches to all the muscles, to the skin, and to the digits, with their intervening web.

The Veins.—Since every part of the body has its vein as well as its artery, there is a rough correspondence between the two kinds of blood-vessel. The arrangement of the principal trunks is, however, very different in the two cases.

On either side of the base of the heart is a large vein called the *precaval* or *vena cava anterior* (Figs. 4 and 25, *pr. cv*) : by turning the ventricle aside, the two precaval veins can be seen to join the anterior ends of the sinus venosus (*s. v*). Each precaval is formed by the confluence of three veins, the *external jugular*, the *innominate*,

and the *subclavian*. The external jugular (*ext. ju*) is formed by the union of a *lingual vein* from the tongue and a *mandibular vein* from the lower jaw. The innominate is formed by the union of an *internal jugular vein* (*int. ju*) from the brain, eye, etc., and a *subscapular vein* (*s. sc*) from the shoulder region. The *subclavian* (*scl*) is formed by the union of the *brachial* (*br*), from the fore-limb, and the *musculo-cutaneous* (*ms. cu*), already noticed, from the superficial parts of the head and part of the skin and muscles of the abdomen.

With the posterior end of the sinus venosus is connected a single large vein, the *postcaval* or *vena cava posterior* (*pt. cv*), a wide vessel lying between the kidneys and extending forwards to the liver (Fig. 5). It runs parallel with and beneath, *i.e.*, ventral to, the dorsal aorta (Fig. 5), from which it is at once distinguished by its greater diameter. Posteriorly it is formed by the confluence of five or six *renal veins* (Fig. 25, *rn*) from each kidney, and it also receives, in the male, *spermatic veins* (*spm*) from the spermaries, and in the female, *ovarian veins* from the ovaries. Anteriorly it perforates the liver; receiving two *hepatic veins* from that organ, and finally enters the sinus venosus.

We have now to consider a striking want of correspondence between the arterial and venous systems of the frog. As you will remember, the dorsal aorta, after giving off the renal arteries, passes backwards and divides into the two iliac arteries for the legs. You might naturally expect a somewhat similar arrangement of the veins, especially if you have studied human physiology and learnt how the posterior (or inferior) vena cava of man is formed by the confluence of the veins from the legs, and receives higher up those from the kidneys. In the frog, as we have just seen, the postcaval does not reach to the hinder boundary of the

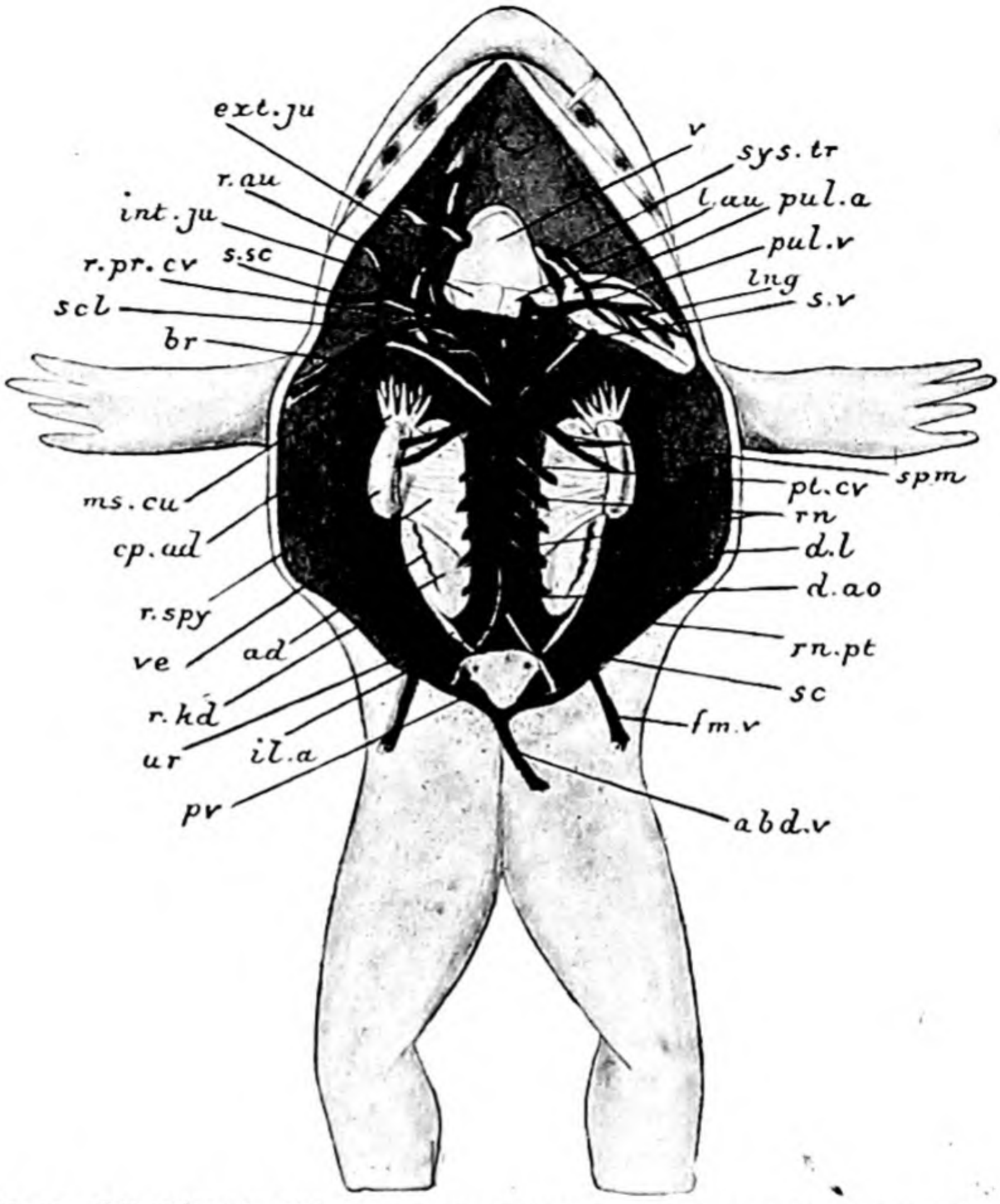


FIG. 25.—Dissection of a Male Frog (*Rana tigrina*), showing the arterial, venous, and urino-genital systems. The liver and the alimentary canal with associated arteries and veins have been removed. The left precaval vein and its branches, the branches arising from the systemic trunks and the dorsal aorta, the carotid trunk on the left side, and the pulmo-cutaneous trunk on the right are not shown. Arteries are coloured red, veins are coloured blue. (Natural size.) (B.L.B.)

abd.v abdominal vein; *ad.* adrenal; *br.* brachial artery and vein; *cp. ad.* fat-body; *d. ao.* dorsal aorta; *d. l.* dorso-lumber vein; *ext. ju.* external jugular vein; *fm.* femoral vein; *il. a.* iliac artery; *int. ju.* internal jugular vein; *l. au.* left auricle; *lng.* lung; *ms. cu.* musculo-cutaneous vein; *pl. cv.* postcaval vein; *pul. a.* pulmonary artery; *pul. v.* pulmonary vein; *pv.* pelvic vein; *r. au.* right auricle; *r. kd.* right kidney; *rn.* renal veins; *rn. pt.* renal portal vein; *r. pr. vc.* right precaval vein; *r. spy.* right spermary; *sc.* sciatic vein; *scl.* subclavian vein; *s. sc.* subscapular vein; *spm.* spermatic vein; *s. v.* sinus venosus; *sys. tr.* systemic trunk; *ur.* ureter; *v.* ventricle; *ve.* vasa efferentia.

kidneys, and the renal veins are the only vessels entering it posteriorly.

In the frog, as a matter of fact, the connections of the veins of the legs are very peculiar. You remember the abdominal vein seen in our preliminary dissection (Figs. 3, 4, and 5, *abd. v*). This vessel, if traced backwards, is found to fork at the posterior end of the abdomen—or more accurately, the single abdominal vein is formed by the confluence of two *pelvic veins* (Fig. 25, *pv*), which can be traced along the base of the leg. Towards the front of the thigh is the principal vein of the leg, the *femoral vein* (Fig. 25, *fm*), which, on emerging from the leg, divides into two branches. One of these is the pelvic vein already seen; it unites with the corresponding vessel of the opposite side to form the abdominal vein (*abd.v*). The other branch of the femoral is called the *renal portal vein* (*rn. pl*); it passes directly forwards, receiving the *sciatic vein* (*sc*) from the back of the leg, and then goes along the outer border of the kidney, finally branching out into capillaries in that organ. It also receives a large *dorso-lumbar vein* (*ds. lmb*) from the muscles of the back. The renal portal vein along with the sciatic vein and the dorso-lumbar vein opening into it, together constitute the *renal portal system.*

The abdominal vein receives, near its posterior end, small veins from the urinary bladder. It passes forwards, as already seen, receiving veins from the abdominal muscles, and quite at its anterior end, a small vein from the heart. It then divides into two branches which enter the liver and branch out in that gland.

The veins from the stomach (*gs*), the intestine (*du, int*), spleen (*spl*), and pancreas run in the mesentery alongside the corresponding arteries. Near the liver they all unite to form a large vessel, the *hepatic portal vein* (Fig. 4, *hp. pt*), which enters and branches out into the liver,

first sending off a branch which joins the abdominal. The abdominal vein and the hepatic portal vein together constitute the *hepatic portal system.*

It must be clearly noted that a portal vein differs from an ordinary vein in that it does not open into a larger vein, but, on the other hand, enters an organ like the liver or the kidney and breaks up into capillaries in the substance of that organ. The blood is collected by other capillaries which form ordinary veins leaving the organ.

Thus the veins from all parts of the body, except the lungs, ultimately discharge into the sinus venosus. The veins from the lungs are quite singular in their course; they unite, in each lung, to form a single *pulmonary vein* (Fig. 25, *pul. v*), which passes dorsal to the sinus venosus, and discharges, with its fellow of the opposite side, into the left auricle.

Character of the Blood in the Arteries and Veins.—There are certain differences between the arteries and veins in respect of the blood they contain. As a rule, the veins contain purple or non-aërated blood, the arteries more or less thoroughly aërated or scarlet blood. But there are certain exceptions. As we shall see in a later chapter, the blood is aërated in the lungs and skin; hence the blood returned from those organs by the pulmonary and musculo-cutaneous veins is aërated. On the other hand, the blood in the pulmo-cutaneous artery is non-aërated.

Flow of Blood.—We must now try to understand the function of this complicated blood-system, and the reason why every part of the body has two vessels, an artery and a vein. That there is some kind of movement of the blood has been hinted in the foregoing description, in which arteries have been described as branching out to various parts, veins as formed by the confluence of smaller veins from various parts.

If an artery were cut in a living frog, the blood would be found to flow out in a series of jerks corresponding with the beats of the heart. Moreover, the blood would flow from the side of the cut nearest to the heart, and the flow might be stopped by tying or compressing the artery on that side, *i.e.*, between the heart and the cut. Evidently, then, the blood in the living animal flows from the heart along the arteries to the various parts of the body, and is propelled by the pulsation of the heart.

If a vein were cut the result would be very different. The blood would flow in a comparatively slow stream and without jerks; it would flow, moreover, from the side of the cut furthest from the heart, so that, in order to stop the bleeding, the vein must be tied or compressed on the far side of the cut. The blood in the veins flows, therefore, towards the heart in an even stream, unaffected by the heart's pulsations.

Thus the blood is driven by the heart to the various parts of the body through the *efferent* arteries, and is returned from the various parts of the body to the heart by the *afferent* veins. Two questions thus naturally arise: how is it that the blood takes this direction and not the other, and how does it make its way from the artery of a given organ into the vein?

Internal Structure of the Heart.—To answer the first question—why the blood leaves the heart by the arteries and returns to it by the veins, and not *vice versâ*—we must examine the heart itself in some detail.

The ventricle is a hollow structure with thick spongy walls and a small cavity (Fig. 26, *v*), and there are two perfectly distinct auricles, the right (*au'*), considerably larger than the left (*au''*), separated from one another by a vertical partition (*a. s.*).

You have already seen that the truncus arteriosus arises from the right side—the frog's right, not yours—

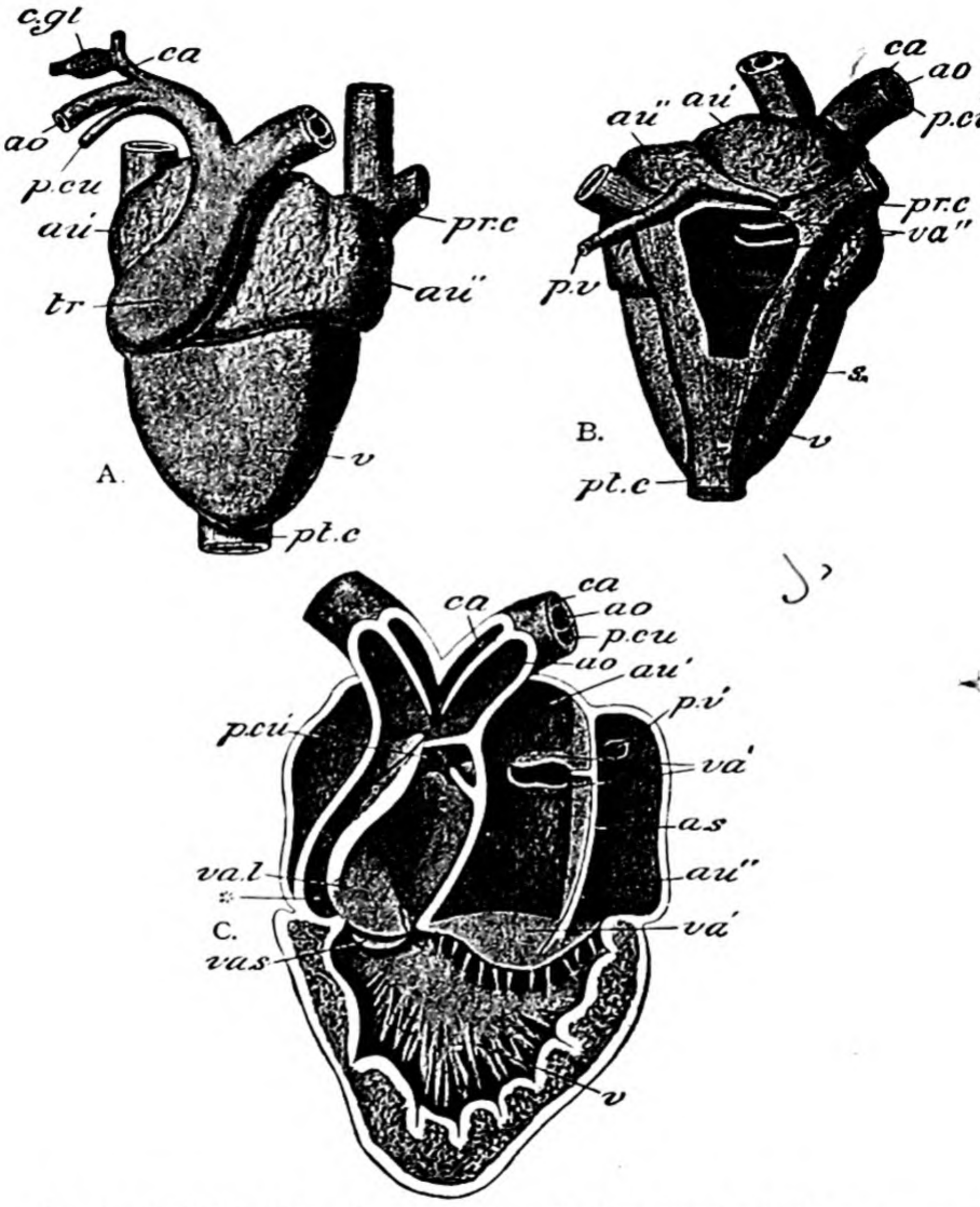


FIG. 26.—Heart of a Frog. A, ventral aspect; B, dorsal aspect, with the sinus vensus opened up; C, interior of the principal chambers, with the ventral wall removed.

ao, systemic arch; *a. s.* interauricular septum; *au'*. right auricle; *au''*. left auricle; *c. a.* carotid arch; *c. gl.* carotid labyrinth; *p. cu.* pulmo-cutaneous arch; *p. cu'*. opening leading to pulmo-cutaneous arch; *p. v'*. opening of the pulmonary veins; *prc.* precaval or anterior vena cava; *pt. c.* postcaval or posterior vena cava; *s. v.* sinus venosus; *tr.* truncus arteriosus; *v.* ventricle; *va'*. dorsal flap of the auriculo-ventricular valve; *va''*. sinu-auricular valve; *va. l.* longitudinal or spiral valve of truncus arteriosus; *va. s.* a semilunar valve. (After Howes.)

of the base of the ventricle. A little to the left of this point there is an aperture through which a bristle can be passed from the ventricle into either of the auricles. Both auricles, then, communicate with the ventricle, by a single *auriculo-ventricular aperture*. This is guarded by two little membranous flaps (*va'*), which spring, one from the dorsal, one from the ventral edge of the aperture, and hang down into the ventricle, to the walls of which they are attached by little tendinous cords, represented in the figure by white streaks. Thus the flaps have the character of folding doors or *valves* opening only one way; they readily flap backwards, *i.e.*, into the ventricle, but are prevented from flapping forwards, or into the auricles, by the tendinous cords attached to them. The two flaps are the *auriculo-ventricular valves*. Their mode of action is easily understood. If the auricles, being full of blood, contract and squeeze themselves together, the pressure will force aside the valves and allow the blood a free passage into the ventricle. On the other hand, if the ventricle contracts, the blood, getting behind the valves, will force them together and close the aperture, the tendinous cords preventing their being driven into the auricles by undue pressure.

The opening of the ventricle to the truncus arteriosus is guarded by three little semilunar or watch-pocket-shaped valves (*va. s*): they are arranged with their edges turned forwards or towards the cavity of the conus, so that any pressure of fluid from the side of the ventricle must force them back and allow ready ingress

into the conus, while pressure in the opposite direction must fill them, bringing their edges together, and so barring the passage. The truncus arteriosus is divided internally by a second row of semilunar valves into two unequal parts, a long *conus arteriosus* or *pylangium* next the ventricle, and a short *bulbus aorta* or *synangium*. In the interior of the conus is a sinuous longitudinal fold or valve (*va. l*) which traverses it obliquely, attached throughout by its dorsal edge, and to one of the semilunar valves anteriorly, but with its ventral edge hanging freely, thus incompletely dividing the conus into a *cavum aorticum*, which begins on the right side and curves round to become ventral, and a *cavum pulmocutaneum*, which begins on the left side and curves round to become dorsal. The cavum aorticum leads more directly to the ventral portion of the synangium, from which the right and left carotid (*ca*) and systemic (*ao*) trunks arise. The pulmo-cutaneous trunks (*p. cu*) spring from the conus by an aperture (*p. cu'*) situated just posteriorly to a valve, and itself guarded by a small valve.

In the dorsal wall of the right auricle is a large transverse aperture, by which the sinus venosus communicates with the auricle; it is therefore called the *sinu-auricular aperture*; its two edges are produced into flaps, the *sinu-auricular valve* (*va''*), which allow free passage from the sinus to the right auricle, but prevent any flow in the opposite direction. In the dorsal wall of the left auricle, situated more anteriorly, is the circular opening of the pulmonary veins (*p. v'*).

Valves of the Veins.—In addition to the valves of the heart, many of the veins contain small watch-pocket valves, all arranged with their concavities directed towards the heart, so as to allow of a free passage in that direction. Any attempt to flow in the opposite direction,

i.e., from the larger to the smaller veins, will result in filling the valves, bringing their edges into contact with the opposite wall of the vein and thus effectually blocking the passage.

Circulation of the Blood.—We see then that an investigation of the structure of the heart shows that fluid can traverse it in one direction only, viz., from the sinus to the right auricle, from the auricles to the ventricle, from the ventricle to the conus, and from the conus to the bulbus aortæ, and so to the arteries. The valves in the veins are so arranged as to allow the blood in these vessels to flow only towards the heart. The experiment of cutting the vessels shows that the blood in the arteries does actually flow from the heart, that in the veins towards the heart. We thus demonstrate that there is not merely a movement but a true *circulation* of the blood, the current starting from the heart, passing by the arteries to all parts of the body, and being returned to the heart by the veins.

Action of the Heart.—The circulation of the blood is effected by the pulsation of the heart. This organ is made of muscle; each of its cavities is to be considered as a bag, the walls of which are formed of muscular fibres crossing one another in various directions and encircling the cavity. We have seen that when an ordinary spindle-shaped muscle contracts, its two ends are brought nearer together. When a hollow muscular bag contracts the effect will be to squeeze the walls together and so diminish the cavity. Hence when any chamber of the heart contracts it must expel a part or the whole of its contained blood. The contraction of the chambers of the heart takes place in regular order: first the sinus, then the two auricles together, then the ventricle, and lastly the conus. The contraction (*systole*) in each case is visible as a sort of throb and is followed

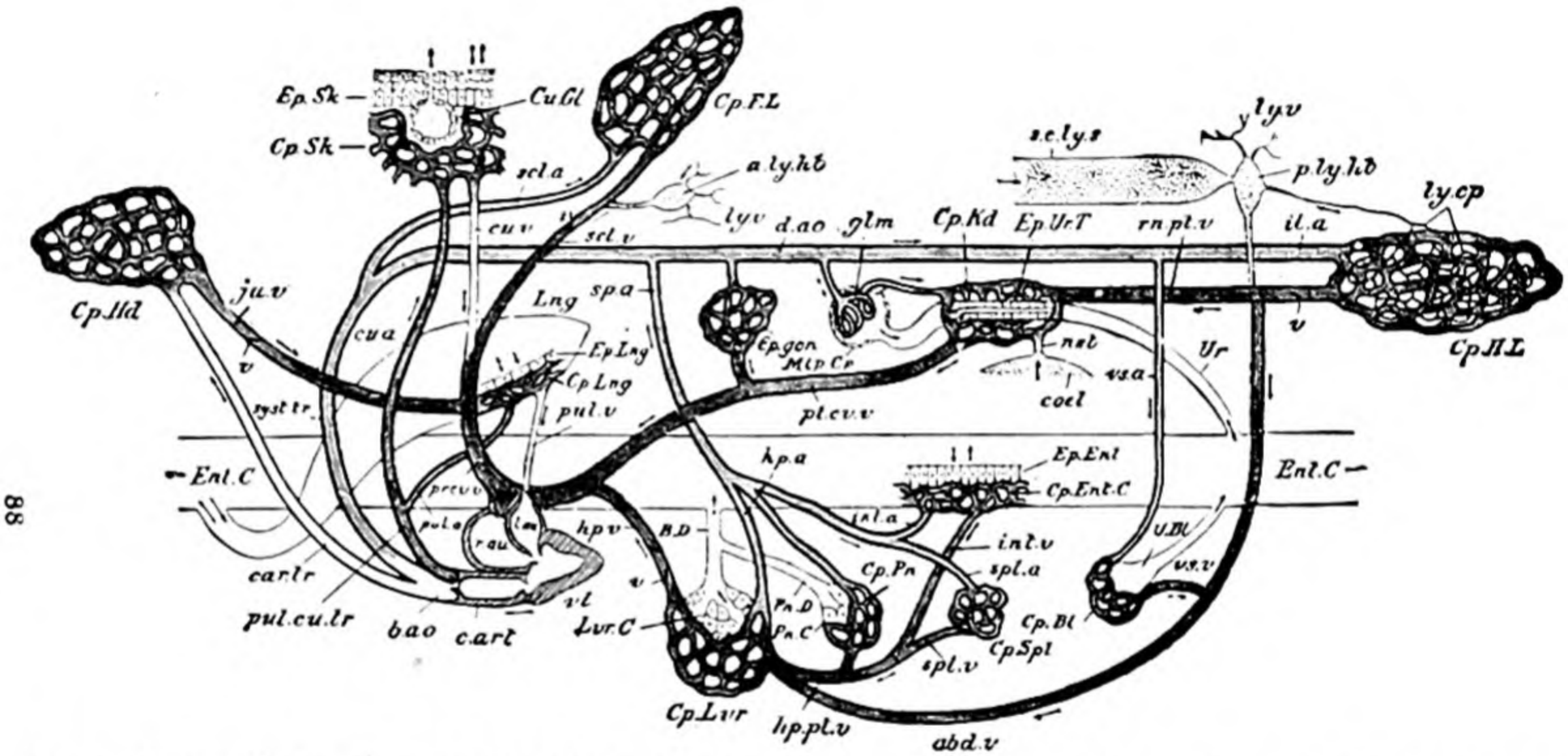


FIG. 27.—Diagram showing the course of the blood and lymph in the Frog, and indicating the losses and gains to the blood during its progress. (For an account of these processes see Chap. IX, where the figure will be again referred to.)

The arteries have thick, the veins and capillaries thin, outlines, the smaller lymphatic vessels are black, the larger are dotted. The degree of aëration of the blood is indicated by the depth of shade, from white (fully aërated) to dark grey (non-aërated). The alimentary canal (*Ent. C.*) is represented as a straight tube having connected with it the lung (*Lng.*), bile-duct (*B. D*), urinary bladder (*U. Bl*), and ureter (*Ur*). The various epithelia and glands are represented diagrammatically by groups of cells, and the kidney is indicated by a single urinary tubule with its Malpighian capsule. The arrows indicate the direction of flow in the vessels and the course taken by the various substances taken into or given out from the blood, glands, etc.

abd. v. abdominal vein; *a. ly. ht.* anterior lymph-heart; *b. ao.* bulbus aortæ; *B. D.* bile-duct; *c. art.* conus arteriosus; *car. tr.* carotid trunk; *cœl.* cœlome; *Cp. Bl.* capillaries of urinary bladder; *Cp. Ent. C.* of alimentary canal; *Cp. F. L.* of fore-limb; *Cp. gon.* of ovary,

or spermary; *Cp. Hd.* of head; *Cp. H. L.* of hind-limb; *Cp. Kd.* of kidney; *Cp. Lng.* of lung; *Cp. Lvr.* of liver; *Cp. Pn.* of pancreas; *Cp. Sk.* of skin; *Cp. Spl.* of spleen; *cu. a.* cutaneous artery; *cu. v.* cutaneous vein; *Cu. Gl.* cutaneous gland; *d. ao.* dorsal aorta; *Ent. C.* alimentary canal; *Ep. Ent.* epithelium of alimentary canal; *Ep. Lng.* of lung; *Ep. Sk.* of skin; *Ep. Ur. T.* of urinary tubule; *glm.* glomerulus; *il. a.* iliac artery; *int. a.* artery to stomach and intestine; *int. v.* vein from stomach and intestine; *ju. v.* jugular vein; *hp. a.* hepatic artery (to liver); *hp. pt. v.* hepatic portal vein; *hp. v.* hepatic vein; *l. au.* left auricle; *Lng.* lung; *Lvr. C.* liver-cells; *ly. cp.* lymph capillaries; *ly. v.* lymphatic vessels; *Mlp. Cp.* Malpighian capsule; *nst.* peritoneal funnels; *p. ly. ht.* posterior lymph-heart; *Pn. C.* cells of pancreas; *Pn. D.* pancreatic duct; *pr. cv. v.* precaval vein; *pt. cv. v.* postcaval vein; *pul. a.* pulmonary artery; *pul. cu. tr.* pulmo-cutaneous trunk; *pul. v.* pulmonary vein; *r. au.* right auricle; *rn. pt. v.* renal portal vein; *scl. a.* subclavian artery; *s. c. ly. s.* sub-cutaneous lymph-sinus; *scl. v.* subclavian vein; *sp. a.* cœliaco-mesenteric artery; *spl. a.* splenic artery; *spl. v.* splenic vein; *s. v.* sinus venosus; *syst. tr.* systemic trunk; *U. Bl.* urinary bladder; *Ur.* ureter; *v.* valve in vein; *vs. a.* vesical artery (to bladder); *vs. v.* vesical vein; *vl.* ventricle.

by a period of rest, during which the chamber regains its former dimensions (*diastole*).

The course of the blood through the heart will now be clear. When the sinus (Fig. 27, *s. v*) contracts, the contained blood, which, coming by the precavals and postcaval, is non-aërated, is acted upon in all directions and might therefore be forced either into the three great veins (*pr. cv. v, pt. cv. v*) or into the right auricle (*r. au*). But the veins are full of blood steadily flowing towards the heart, and any regurgitation is further prevented by their valves: the right auricle, on the other hand, has finished its contraction and is now relaxing; it is therefore empty. Thus, on the principle of least resistance, the contraction of the sinus fills the right auricle with blood from the great veins, and the sinus itself is refilled from the same source as soon as it begins to relax.

Immediately after the sinus has ceased to contract the two auricles contract together: the right, as we have seen, has just been filled from the sinus, the left (*l. au*) is full of aërated blood brought to it by the pulmonary vein (*pul. v*). The presence of the sinu-auricular valves prevents the blood in the right auricle from being forced back into the sinus: that in the left auricle is prevented from being forced back into the pulmonary veins by the steady onward flow in the latter. On the other hand

the ventricle is beginning to relax and is empty. Consequently the auriculo-ventricular valves are forced back into the ventricle (*vl*) and the blood from both auricles flows into and fills that chamber, the right half of which becomes filled with non-aërated, the left with aërated blood, the two taking an appreciable time to mingle, owing to the spongy character of the ventricular wall.

The instant it is thus filled, the contraction of the ventricle begins. As it does so the blood, getting behind the auriculo-ventricular valves, forces them together, and thus prevents any backward flow into the auricle. At the same time the semilunar valves at the entrance of the conus (*c. art*) are pushed aside and the blood flows into that chamber. Since the conus opens from the right side of the ventricle, the blood first entering it will be non-aërated; there will then follow a certain amount of mixed blood; and finally, as the ventricle reaches the limit of its contraction, the aërated blood from its left side will be forced into the conus (compare Fig. 26).

Two alternative courses are now open to the blood: it can pass either directly from the conus into the pulmo-cutaneous trunk (*pul. cu. tr*), or make its way into the bulbus aortæ (*b. ao*). As a matter of fact the non-aërated blood first entering the conus is diverted almost exclusively into the cavum pulmo-cutaneum, and passes into the pulmo-cutaneous trunks, owing to the circumstance that there is little resistance in the limited blood-system of the lungs, while that in the systemic and carotid trunks is very great. Hence the blood first received into the conus from the ventricle, which, as we have seen, is non-aërated, goes immediately to the lungs and skin to be aërated.

As these are filled, their resistance increases, and the mixed and later the aërated blood flows through the

cavum aorticum into the bulbus aortæ. The conus also by its contraction brings the free ventral edge of the longitudinal valve into contact with its ventral wall, and the blood passing on the right of the longitudinal valve flaps it over the pulmo-cutaneous aperture and prevents any further blood entering it. In the bulbus, again, the question of pressure comes in. It is easier for the blood to make its way into the wide systemic trunks (*syst. tr*) uniting immediately into the long dorsal aorta (*d. ao*) than into the comparatively narrow carotid trunks (*car. tr*), obstructed by the carotid labyrinths. Hence, the non-aërated blood having been mostly driven into the pulmo-cutaneous trunk, the mixed blood, from the middle part of the ventricle, goes into the systemic trunk, and thence to the various arteries supplying the limbs (*scl. a, il. a*) and the viscera (*sp. a*, etc.). Finally, when the pressure is sufficiently raised in the systemic trunks, the remaining blood, which, coming from the left side of the heart, is aërated, is pumped into the carotid trunks (*car. tr*), and thence to the head.

Thus, owing to the arrangement of the valves, and to the varying pressures in different parts of the vascular system, the non-aërated blood returned from the various parts of the body to the heart is mostly sent to the lungs and skin to be aërated. Mixed blood is sent to the trunk, limbs, and viscera, while for the head with its contained brain—the directing and controlling organ of the whole animal—a special supply of pure, aërated blood is reserved.

We see then that the course of the circulation may be proved, as a simple matter of induction, from the structure of the heart and its valves, the direct observation of its beat, and the manner in which the flow from cut vessels takes place. It was by observation and experiments of this kind that the circulation of the

blood in the higher animals was demonstrated by William Harvey in the seventeenth century. But the final and most conclusive proof of the circulation—from directly observing the flow—became possible only after the invention of the microscope. This instrument, by furnishing a sufficiently high magnifying power, allows us to see for ourselves the actual movement of the blood in an animal or organ of sufficient transparency; and at the same time clears up the question, previously insolvable, of how the blood, having reached a given part or organ by the arteries, finds its way into the veins to begin its return journey.

The Circulation in the Frog's Web.—There are two parts in the frog transparent enough to allow of the blood-flow being seen in them—the web of the foot and the mesentery. Of these the web is the most convenient, and can be examined under the microscope without any injury to the animal.

The Capillaries.—If you have the makings of a naturalist, you will acknowledge the sight to be one of the most wonderful you ever saw. In the thickness of the web is an irregular network of minute blood-vessels, called *capillaries* (Fig. 28), and through them the blood is seen to flow with great rapidity, its course being made especially evident by the minute particles or *corpuscles* it contains, the structure of which we shall study later on (Fig. 30). You will also notice much larger vessels, the smallest arteries and veins. The arteries (*a*) are distinguished by the fact that the blood in them flows in the direction from the leg towards the margin of the web, while in the veins (*v*) it takes the opposite direction. You must remember, however, that under the microscope everything is reversed; right appears left and left right, and a current actually flowing towards the observer appears to go in the opposite direction.

By careful examination you will see that both arteries and veins are in connection, by minute branches, with the capillary network, and will be able to trace the

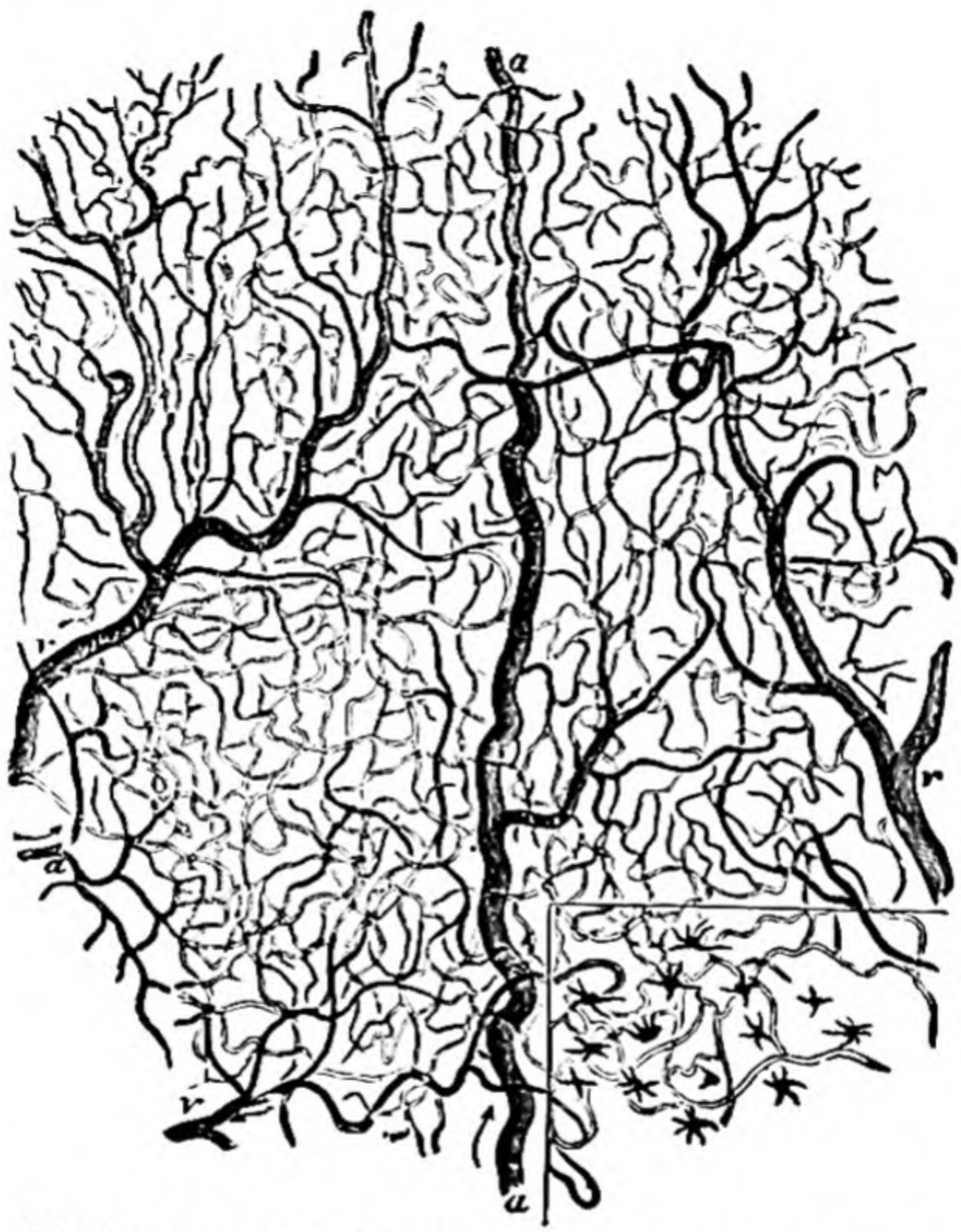


FIG. 28.—Blood-vessels of the web of a Frog's foot seen under a low magnifying power. *a*. small arteries; *v*. small veins. The minute tubes joining the arteries to the veins are the capillaries. The arrows show the direction of the circulation. In the small portion marked off, the pigment cells of the skin, which occur throughout the web, are also represented. (From Huxley's *Physiology*.)

blood from an artery, through the capillaries, into a vein.

The same thing can be seen in other transparent organs; and by injecting the vascular system with a

fluid injection-mass, such as gelatine suitably coloured, it can be proved that all parts of the body are permeated with a capillary network into which the blood is passed by the arteries, and from which it is received into the veins.

Thus by means of the microscope we are able to take the final step in demonstrating the circulation. The fact that the blood can flow in one direction only is proved by the disposition of the valves of the heart and of the veins, but the passage of the blood from the smallest arteries to the smallest vein by a connecting system of minute tubes or capillaries can be proved only by the employment of considerable magnifying powers. We see that the vascular system of the frog is a closed system of vessels: the blood is everywhere confined within definite tubes through which it flows in a definite direction, never escaping, as in some of the lower animals, into large irregular spaces among the tissues.

The Lymphatic System.—Included in the vascular system are certain cavities and vessels containing lymph, and together constituting the *lymphatic system*. We have already noticed the subcutaneous lymph-sinuses (p. 16, and Fig. 27, *s.c.ly.s*) and the sub-vertebral lymph-sinus (p. 25, Fig. 6, *s.v.ly.s*). There are also found in nearly all parts of the body delicate, thin-walled, branching tubes, the *lymphatic vessels* (Fig. 27, *ly. v*). Unlike the blood-vessels, the lymphatics are all of one kind, there being no distinction into anything of the nature of arteries and veins. They arise in *lymph-capillaries* (*ly. cp*), which are, as it were, interwoven with the blood-capillaries, but have no connection with them. By the lymph-capillaries the fluid which has exuded from the blood in its passage through the tissues is taken up and passed into the lymphatic vessels or sinuses, and these

in their turn finally communicate with certain transparent muscular organs called *lymph-hearts*. Of these there are two pairs. The anterior lymph-hearts (*a. ly. ht*) lie, one on either side, beneath the supra-scapula and just behind the transverse process of the third vertebra : the posterior pair (*p. ly. ht*) are situated one on each side of the posterior end of the urostyle. These organs pulsate regularly, like miniature hearts, and pump the lymph into the veins, the anterior pair communicating with the subclavian, the posterior with the renal portal vein.

The lymphatics of the alimentary canal have an important function to perform in that they absorb the fatty portions of the food (p. 72). The fluid they contain has a milky appearance, owing to the presence of minute suspended fat-globules, and for this reason they receive the name of *lacteals*.

The cœlome is really a great lymph-sinus (Fig. 27, *cæl*). It communicates with the veins of the kidneys through certain microscopic apertures called *nephrostomes* (*nst*).

The **spleen** (p. 21, and Fig. 4, *spl*) has important relations with the blood- and lymph-vessels, and probably acts as a blood-filter, removing old and worn-out red corpuscles and foreign micro-organisms from the blood. The white corpuscles of the blood divide and multiply in numbers in the spleen.

Ductless Glands.—There are found in the different parts of the body small glands which do not possess any ducts and pour their secretions directly into the blood-stream. The secretions are minute in quantity, but are carried to distant parts of the body, influencing their working in various ways. There is a pair of **thyroid** glands. Each is a small rounded or lobulated body, situated ventral to and in close connection with the

external jugular vein. The thyroids secret a substance rich in iodine. Nothing is known of the functions of the thyroid in the frog, but in higher vertebrates, the removal of the gland leads to serious disturbances and proves fatal. The **thymus** is another such gland. It is a small, oval, reddish-looking body, situated close behind the tympanic membrane, near the angle of the jaw. The **adrenals** are a pair of yellow streak-like bodies lying one on the ventral surface of each kidney.

The internal secretions or *hormones* of these ductless glands and various other organs perform important co-ordinating functions in the body.

CHAPTER VII

THE FROG (*continued*): THE MICROSCOPICAL EXAMINATION OF THE SIMPLE TISSUES

BEFORE carrying our inquiries any further into the anatomy and physiology of the frog it will be necessary to devote some consideration to its microscopic structure or *histology*, since there are many matters in connection with the various organs which can be further elucidated only by the examination of the minute structure of the organs as revealed by the microscope.

Let us, first of all, examine a drop of the frog's **blood** under the low power of the microscope. It will at once be seen that the blood is not a simple homogeneous fluid, but that it contains a large number of minute solid bodies floating in it. These are called by the general name of *blood-corpuscles*: the fluid part of the blood in which they float is called the *plasma*. At first, owing to currents in the fluid, the corpuscles will be found to move to and fro, but after a time they come to rest. Under the high power you will notice that the corpuscles are of two kinds. The greater number of them are regularly oval in form (Fig. 29, C), and of a yellow colour. If the drop of blood is thick enough in one part for the corpuscles to lie over one another, so that the light passes through two or three layers of them to reach the

eye, they will appear red: they are hence called *red corpuscles*. Frequently they are seen turned on edge (D), and their appearance in this position shows them to be flat, oval discs with a swelling in the centre. They are about $\frac{1}{40}$ of a millimetre (about $\frac{1}{1000}$ inch) in long diameter.

Among the red corpuscles are found, in much smaller numbers, bodies not more than half the long diameter of the red corpuscles in size, quite colourless, distinctly granular—so as to have the appearance of ground glass—and with a slightly irregular outline (Fig. 29, A).

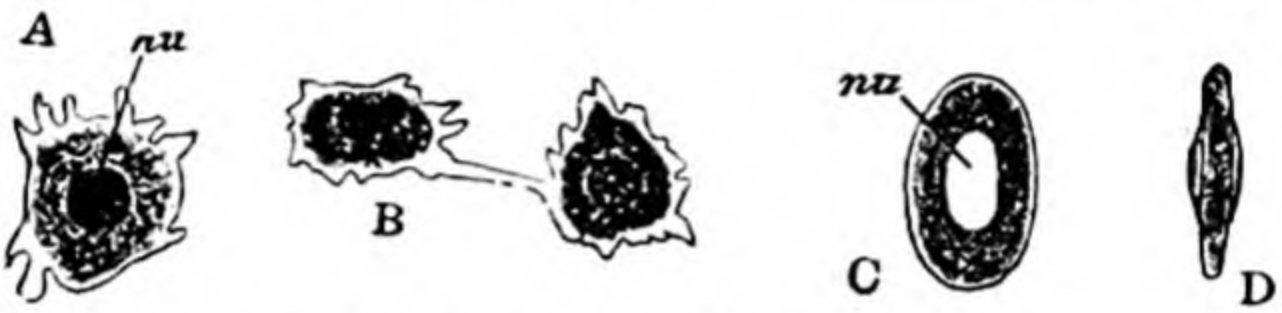


FIG. 29.—Blood-corpuscles of the Frog. (× 525.)
A, colourless corpuscle; B, the same in process of division; C, red corpuscle, surface view; D, the same, edge view, *nu*. nucleus. (From Parker's *Biology*.)

These are the *colourless corpuscles* or *leucocytes*. They are not flat, like the red corpuscles, but have the form of irregular lumps.

The plasma, like the leucocytes, is quite colourless, so that the colour of the blood is seen to be due entirely to the large number of red corpuscles it contains.

If the drop of blood has been prepared and examined under the high power with sufficient rapidity, a remarkable phenomenon can be made out with regard to the colourless corpuscles. This can be most easily demonstrated by making a series of outline sketches of the same leucocyte at intervals of a minute or two. You will then notice that the sketches all differ from one another: in one there will perhaps be a little projection going off to the right; in the next this will have disappeared and a similar projection will have appeared on the left, and so

on. As a matter of fact, as long as the blood is quite fresh, the leucocytes are in constant movement, sending out and withdrawing little processes of their substance called *pseudopods* or "false feet," by means of which they can crawl slowly along like independent living things. These very peculiar and characteristic movements resemble those of a microscopic animalcule known as Amœba, and are therefore called *amœboid movements*. Occasionally a leucocyte may be seen to elongate itself and divide into two (Fig. 29, B) : this is a case of what is called *simple fission*. The red corpuscles neither move nor divide. Both kinds of corpuscles are unit masses of living substance known as *protoplasm*.

If a drop of some dye or staining fluid be run in under the cover-glass, the corpuscles will be seen to become rather faint in outline, transparent, and lightly tinted; but the most obvious effect is that in the middle of each is seen a rounded or oval granular body (*nu*) deeply stained by the dye, so as to make a very well-defined coloured area in the interior of the corpuscle. This body is called the *nucleus* : it is present both in the red and the colourless corpuscles.

By adding to a fresh drop of blood, in the same manner, a drop of weak acetic acid, the nucleus again becomes distinct, while the body of the corpuscle is rendered very transparent and almost invisible : indeed it finally disappears altogether. It is thus proved that the corpuscles, both red and colourless, consist of a substance which is known as *cytoplasm*, but slightly affected by dyes, and soluble in weak acids; and enclosed in this is a nucleus, stained by dyes, and unaffected by weak acids. Both nucleus and cytoplasm consist mainly of proteins (p. 68), together with water and a small proportion of mineral matters.

When distilled water is added to a drop of blood on

the slide, the corpuscles are seen to swell up and become partly dissolved: the red colouring-matter of the red corpuscles is dissolved out, the plasma becoming tinged with yellow. Thus the colouring-matter is evidently a distinct substance from the protoplasm, and is called *hæmoglobin*. It is characterised, among other things, by a strong attraction for oxygen: in combination with that gas it assumes a bright scarlet colour; when deprived of oxygen, it becomes purple. This affinity for oxygen accounts for the change undergone by the blood when exposed to the air, as described on p. 82.

Coagulated blood, as seen under the microscope, is characterised by the plasma being traversed by extremely delicate threads, forming a sort of network in which the corpuscles are entangled. These threads are formed of a substance called *fibrin*, which is separated from the plasma during coagulation, the remaining or fluid portion of the plasma constituting the *serum*. We may therefore express the coagulation of the blood in a diagrammatic form as follows:—

Fresh Blood.		*Coagulated Blood.*
Plasma . .	Serum + Fibrin	Clot.
Corpuscles . . .		

Having observed the microscopic characters of a drop of blood, let us examine once more the circulation in the web, this time under the high power (Fig. 32). The red corpuscles (*F*) can be seen streaming through the vessels, those in the capillaries in single file, those in the small arteries and veins, two or more abreast: as they pass through narrow capillaries or round corners, they become bent or squeezed (*G*, *H*). The leucocytes (*I*) travel more slowly and often stick to the sides of the vessels.

GOVT. GIRLS COLLEGE LIBRARY

Squamous or Pavement Epithelium.—By collecting the surface castings of a frog's skin and examining a very small piece in a drop of water, after staining them, the superficial layer of the skin will be found to be made up of flattened, roughly hexagonal plates (Fig. 30 and Fig. 32, C, D) set closely together, like the tiles of a mosaic pavement. Each plate has a nucleus, and, from its flattened form, is distinguished as a *squamous* or scale-like epithelial cell.

FIG. 30.—Squamous epithelial cells from the Frog's skin. (× 300.)
nu. nuclei.

Columnar Epithelium.—By carefully scraping a small piece of the inner surface of the mucous membrane of the intestine and teasing it into the smallest possible particles, it will be found that the process has detached numerous, minute, conical bodies, about $\frac{1}{30}$ mm. ($\frac{1}{750}$ in.) in length, polygonal in transverse section, and having one end flat and the other more pointed (Fig. 31). These bodies are called *columnar epithelial cells*: in the natural position they lie closely cemented to one another, like the blocks of a wood-pavement, their flattened ends facing the cavity of the intestine, while their narrower ends abut against the submucosa (p. 64). The epithelial cells together form an *epithelium* or *epithelial layer* of the mucous membrane directly bounding the cavity of the alimentary canal.

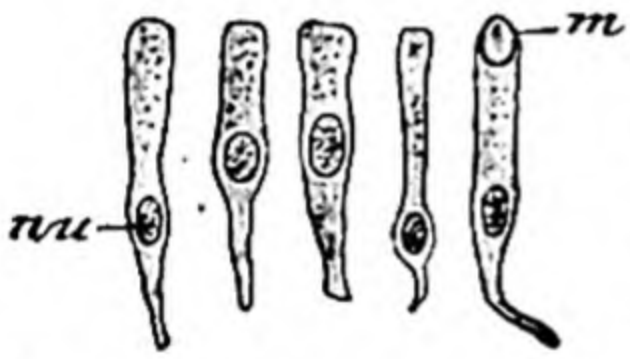


FIG. 31.—Columnar epithelial cells from the Frog's intestine. (× 500.)
m. droplet of mucus exuding from cell; *nu*. nucleus.

Each cell consists of cytoplasm containing a rounded, granular nucleus (*nu*), which is made very conspicuous

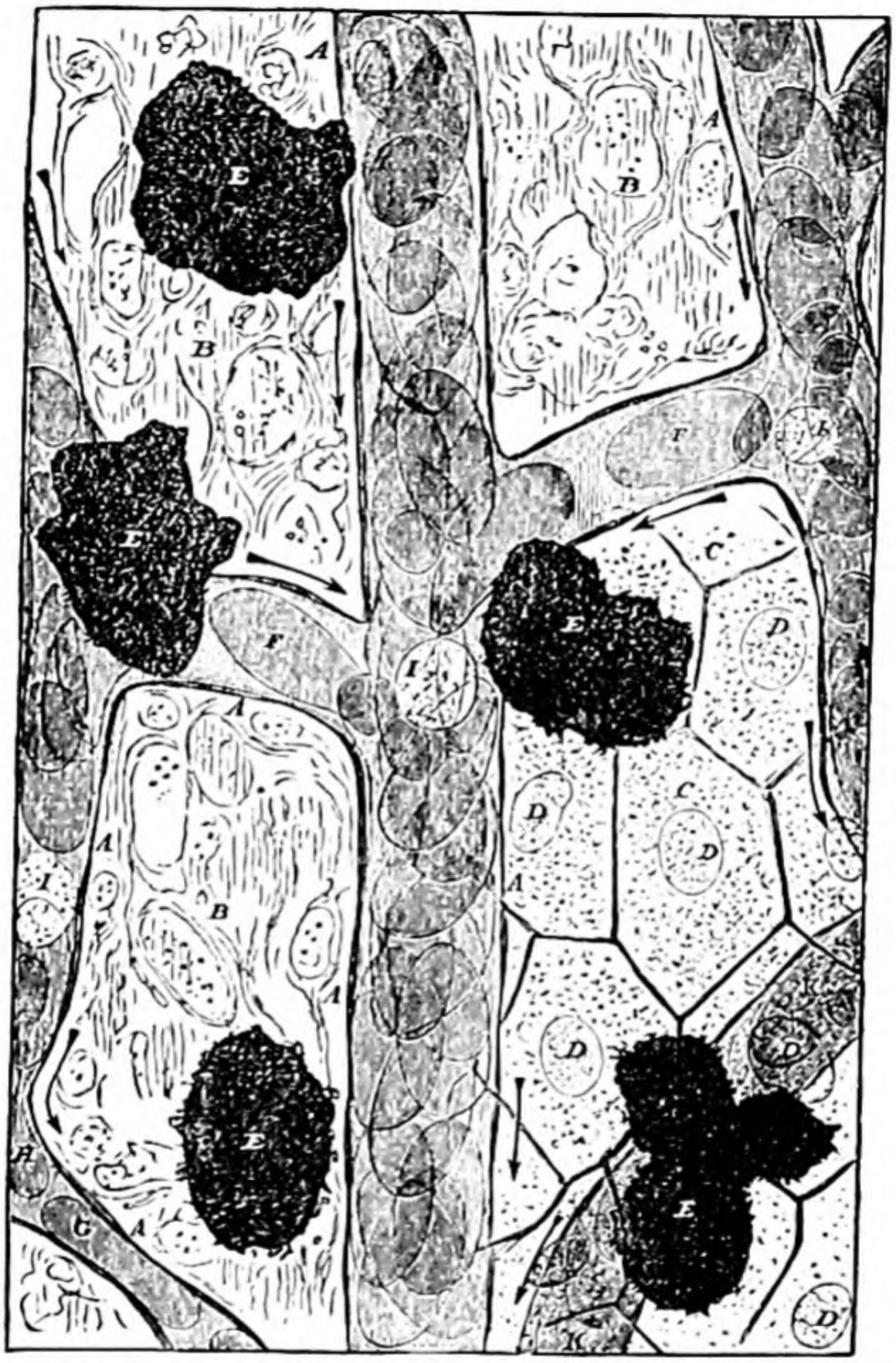


FIG. 32.—The circulation in the Frog's web, under a high power.
A, wall of capillaries; *B*, tissue of the web in which the capillaries lie; *C*, epidermis-cells; *D*, their nuclei; *E*, pigment-cells; *F*, red corpuscles; *G*, *H*, red corpuscles being squeezed through a narrow capillary; *K*, capillary seen through the epidermis; *I*, colourless corpuscles. (From Huxley's *Physiology*.)

by staining, and in which are one or more small bodies or *nucleoli*. Certain of these cells have a space towards their free ends containing slime or *mucus*, and thus have the form of little cups or goblets : they are known as *goblet-cells* (*see* right-hand cell in Fig. 31).

Fig. 33.—Ciliated epithelial cells from the mucous membrane of the frog's mouth. (× 500.) (From Parker's *Biology*, after Howes.)

Ciliated Epithelium.—By the same method the mucous membrane of the mouth is also seen to be lined by an epithelium, but the cells comprising it (Fig. 33) are broader in proportion to their length, and each is produced on its free surface into a number of delicate, transparent threads of protoplasm called *cilia*, which in the living condition are in constant movement, lashing backwards and forwards like minute whip-lashes, or, more accurately, like the blades of grass in a field when acted upon by a strong wind. If you happen to get under the microscope a good-sized bit of mucous membrane with the cells in position, you will see that the cilia produce a strong current by which small particles are swept along, while detached cells swim about, like little independent animals, by the action of their own cilia. These *ciliated epithelial cells*, like the ordinary *columnar* cells of the intestine, are made of protoplasm, and each consists of cytoplasm containing a nucleus with one or two nucleoli clearly brought into view by staining.

The action of the cilia can be demonstrated, on a large scale, by placing a freshly-killed frog on its back, turning back or cutting away the lower jaw, and placing a very small cube of cork on the roof of the mouth near to the projection due to the eyes. The cork will be slowly swept back towards the throat.

Meaning of the word "Cell."—We see thus that

the body of the frog is partly made up of distinct elements, which, under a considerable diversity of forms, exhibit the same essential characters. Each is a unit mass of living *protoplasm* and is designated a *cell*. Each cell consists of a clear or more or less granular *cytoplasm* containing in its interior a rounded body, the *nucleus*, the latter specially distinguished by the affinity of parts of its substance for colouring-matters.

Unstriped Muscle.—Examination of a teased preparation of the muscular coat of the intestine, stomach, or urinary bladder will show that it is composed of delicate fibres (Fig. 34) tapering at both ends, and each with a nucleus in the middle. These are called *smooth* or *unstriped muscular fibres*: they are obviously cells which have undergone a great elongation in length.

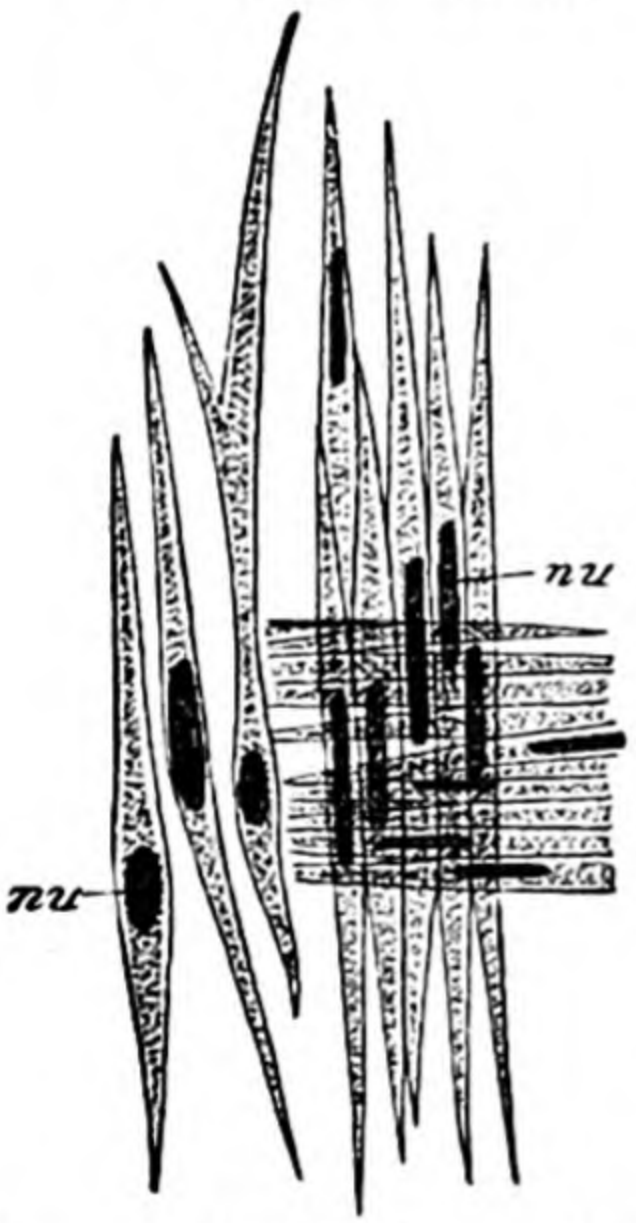


FIG. 34.—Unstriped muscular fibres from the Frog's intestine. (× 500.)
To the right are shown fibres from the longitudinal and circular layers (see Chap. VIII) crossing one another; to the left isolated fibres. (After Howes.)

During the peristaltic movements of the intestine (p. 72) each fibre alternately contracts and relaxes, becoming shorter and thicker during the former process, like the large muscles of the body (p. 58). The movements in this case, however, are not under the control of the will, and unstriped muscular tissue is therefore often spoken of as *involuntary muscle*.

Contractility of Protoplasm.—We have now studied three different kinds of movement in cells:—*muscular move-*

ment in the unstriped muscle-fibres, *ciliary movement* in the ciliated epithelial cells, and *amœboid movement* in the colourless blood-corpuscles. Muscular movement is due to the fibre undergoing a sudden shortening in a particular direction and a consequent approximation of its two ends. Ciliary movement is due to the alternate bending and straightening of the cilia; and the bending of a cilium in a particular direction is caused by the protoplasm of which it is composed shortening or contracting on the side towards which it bends. Amœboid movement is the protrusion and withdrawal of irregular processes of the cell: this results from the protoplasm undergoing a contraction or squeezing in a given direction, as a consequence of which one part of its substance is drawn in and another pushed out. Hence all three kinds of movement are movements of *contraction*; and *contractility*, or the power of contraction, may be considered as a general property of protoplasm.

Striped Muscle.—If a small piece of any of the body-muscles is carefully teased out with the grain, *i.e.*, in the direction of the length of the fibres, so as to break away the connective-tissue binding them together, the fibres, which are much larger than those of smooth muscle, will readily separate from one another, and they will be seen to be long and cylindrical. Under the microscope each fibre shows a delicate transverse striation (Fig. 35), being made up of alternate bright (*b*) and dim (*d*) bands—or more accurately discs, the fibre being cylindrical—set at right angles to its length. Hence the ordinary body-muscles or *voluntary muscles* are composed of *striped muscular fibres*.[1] In addition to the transverse striation a fainter longitudinal striation is more or less distinctly visible.

[1] The muscles of the heart, although not under the control of the will, are transversely striated; but their structure differs from that of ordinary striped voluntary muscle.

Each fibre is covered by a delicate membrane (*s*), called *sarcolemma*, beneath which nuclei (*n*) occur at intervals. It will be seen that striped muscle, unlike the tissues previously considered, does not appear to be composed of cells, although the occurrence of nuclei seems to indicate their presence. In the embryo,

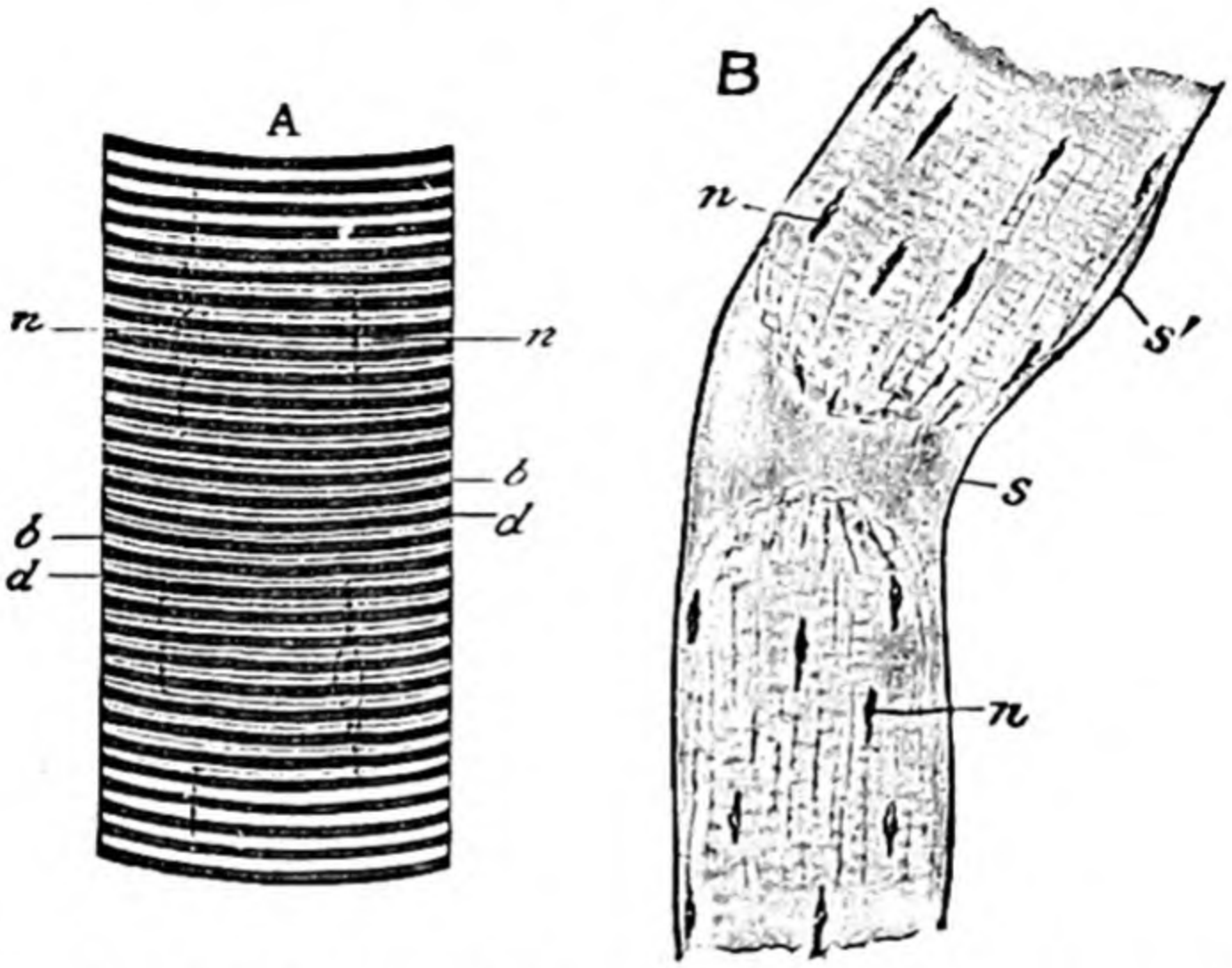


FIG. 35.—A, part of a fresh muscular fibre of a Frog. B, the same after treatment with distilled water followed by methyl-green. (× about 150.)
b. bright bands; *d*. dim bands; *n*. nuclei; *s*, *s'*. sarcolemma, rendered visible as a minute blister (*s'*) by absorption of water and by the rupture of the muscle-fibre at *s*. (A, from Huxley's *Physiology*.)

however, the muscle is formed of ordinary nucleated cells, which, as growth goes on, increase in length while their nuclei multiply by fission, each enormously elongated cell thus containing a considerable number.

Connective-tissue.—We will next examine a piece of the delicate web of connective-tissue which binds the muscles together.

Under the high power, connective-tissue is seen to be

composed of a sort of irregular network of delicate bundles of wavy fibres called *white connective-tissue fibres* (Fig. 36, *w*), which cross one another in all directions. Amongst them are found single fibres sweeping across the field in bold curves and called *elastic fibres* (*e*) : it is

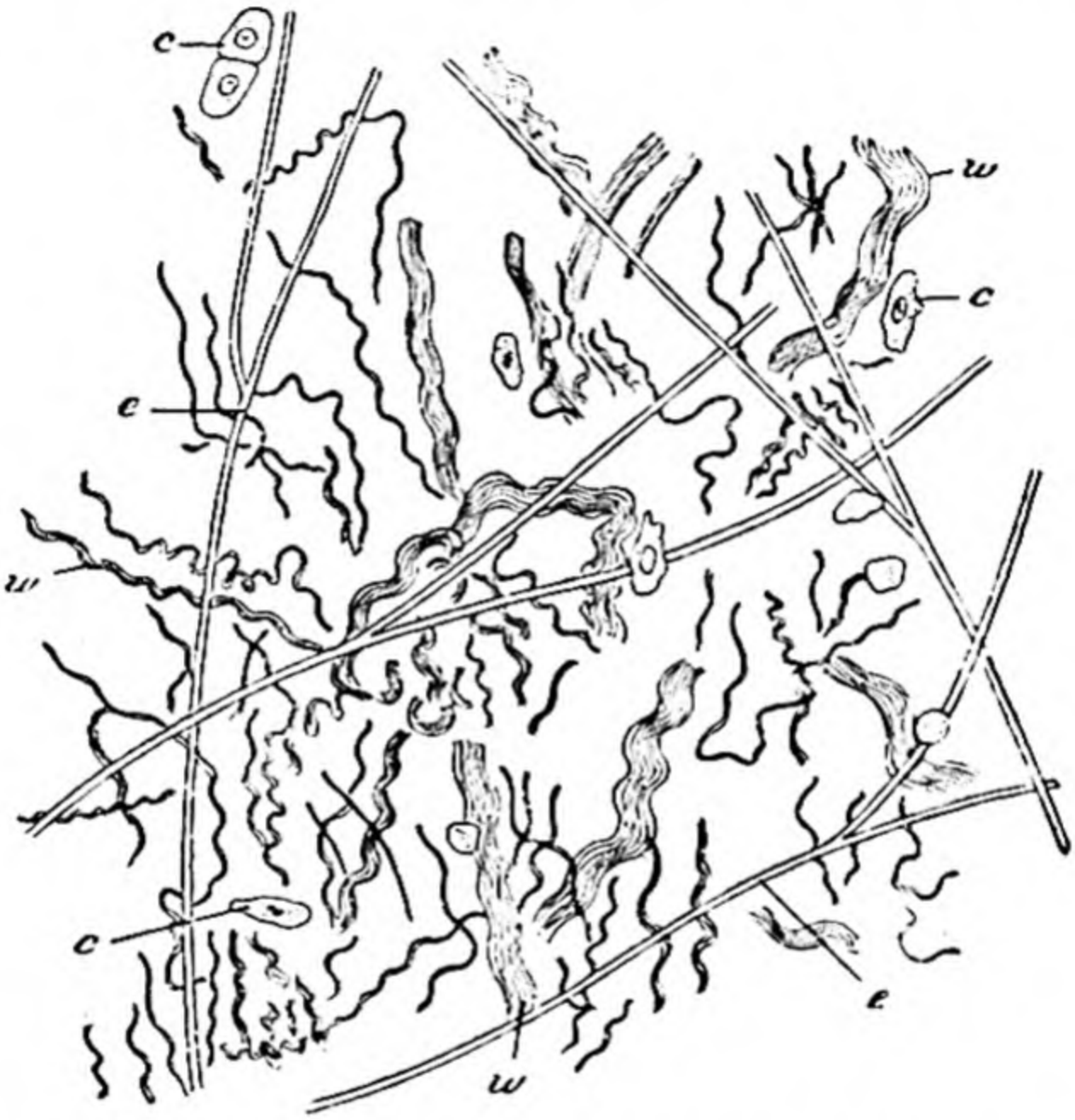


FIG. 36.—Connective-tissue from between muscles of the Frog's legs. (× about 200.) *c*. cells; *e*. elastic fibres; *w*. white fibres :—all of which are imbedded in a delicate matrix not specially indicated in the figure.

owing to their elasticity that the tissue cannot be spread out when wet. Scattered among the fibres are numerous nucleated cells (*c*) of very varied and often irregular form : these are the *connective-tissue cells*. The fibres, as well as the cells, are imbedded in a soft, homogeneous, *ground-substance* or *matrix*.

Thus connective-tissue consists partly of cells, but between these, and forming the main substance of the tissue, is a matrix or *intercellular substance*, enclosing fibres. In the embryo the tissue consists of closely-packed cells, but, as development proceeds, these separate from one another, and the ground-substance is formed between them.

Cartilage.—The ordinary clear or *hyaline* variety of this tissue is conveniently studied by examining a piece of the thin edge of the omo- or xiphi-sternum, or by

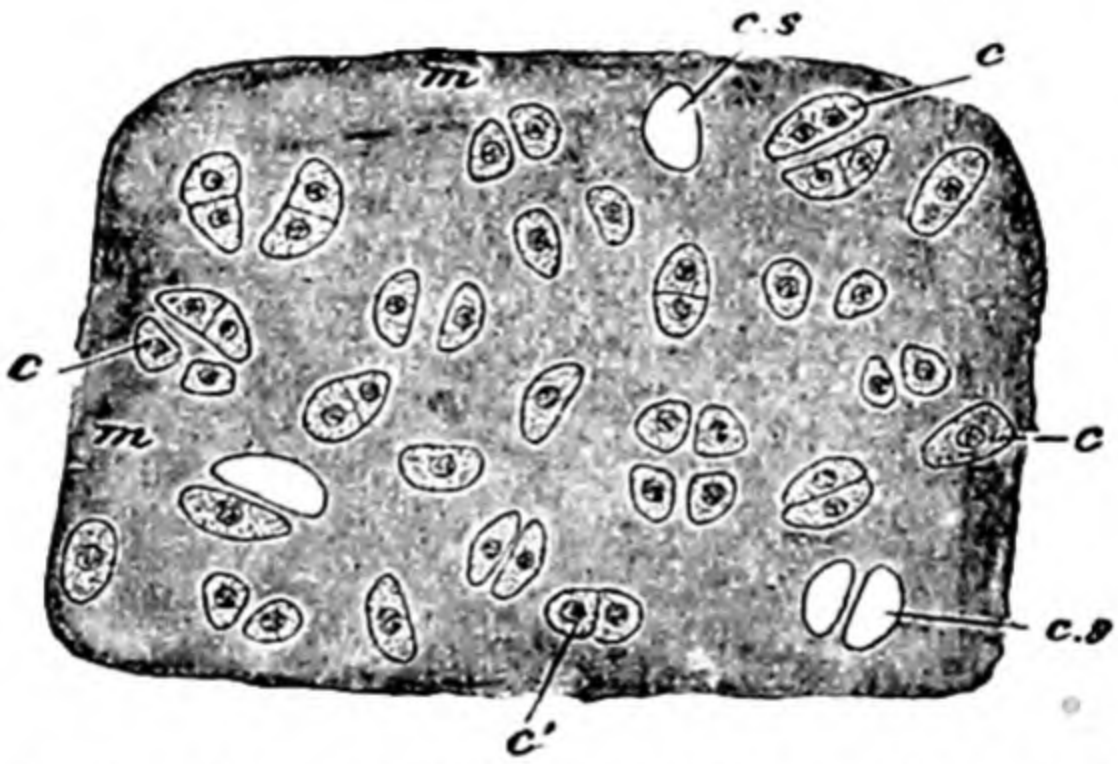


FIG. 37.—Section of cartilage, from the head of the Frog's femur. (× 200.)
c. cells; *c'*. cells undergoing fission; *c. s*. empty cell-space; *m*. matrix.

taking a thin section with a razor of the head of the humerus or femur.

Cartilage consists of a tough, elastic, transparent, homogeneous matrix (Fig. 37, *m*) containing numerous cavities or *cell-spaces* (*c. s.*), in each of which is a nucleated cell (*c*). The cell-spaces, or *lacunæ*, are in many cases arranged in groups of two or four, sometimes close together, sometimes with a narrow bit of matrix or intercellular substance between them. This is due to the fact that cartilage grows by the cells undergoing

binary fission, so that two cells are formed in one cell-space: the two then gradually separate from one another and intercellular substance is formed between them. In the embryo, this tissue consists entirely of closely-packed cells which gradually separate and form a structureless matrix which is firm and elastic, and which in some parts (pp. 44 and 46) may become calcified.

Bone.—As we have already seen (p. 51) bone is formed of two constituents, a basis of animal matter, in which

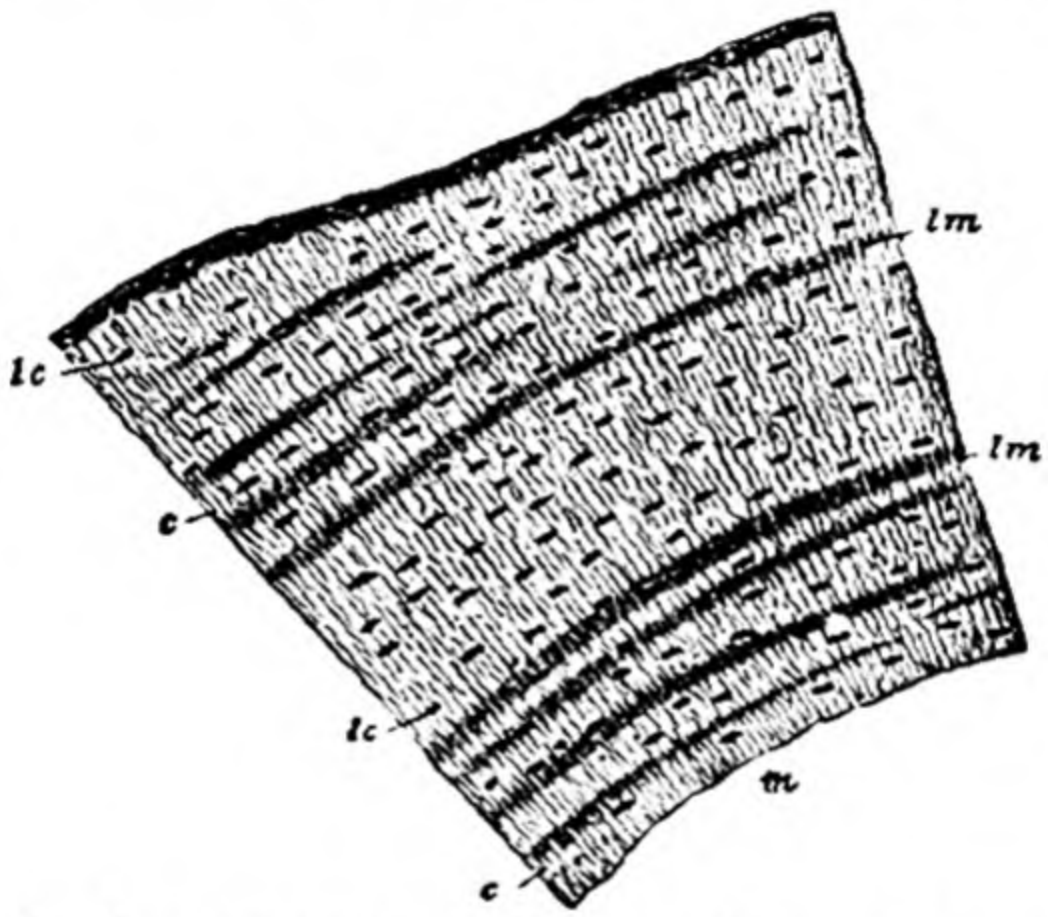


FIG. 38.—Transverse section of dry femur of Frog. (× about 125. *c*. canaliculi; *lc*. lacunæ; *lm*. lamellæ; *m*. marrow-cavity.

mineral matter—calcium phosphate and carbonate—is deposited. In microscopic examination we may therefore investigate either the mineral matter by examining dried bone, or the animal matter by examining decalcified bone.

A thin section of a dried long bone, such as the femur, shows that it is formed of very numerous thin layers or *lamellæ* (Fig. 38, *lm*), surrounding and concentric with the marrow-cavity. The lamellæ contain numerous

cavities, the *lacunæ* (*lc*), with delicate, branching tubes, the *canaliculi* (*c*), radiating from them in all directions. Both lacunæ and canaliculi commonly appear black, owing to their being filled either with air or with bone-dust produced in grinding the section.

In a section of decalcified bone (Fig. 39) the marrow is seen to be surrounded by lamellæ of a delicate fibrous substance, arranged in two layers, an outer (*b*) having the periosteum (*p*) closely investing it, and an inner (*b'*) in contact with the marrow. In the fibrous substance of

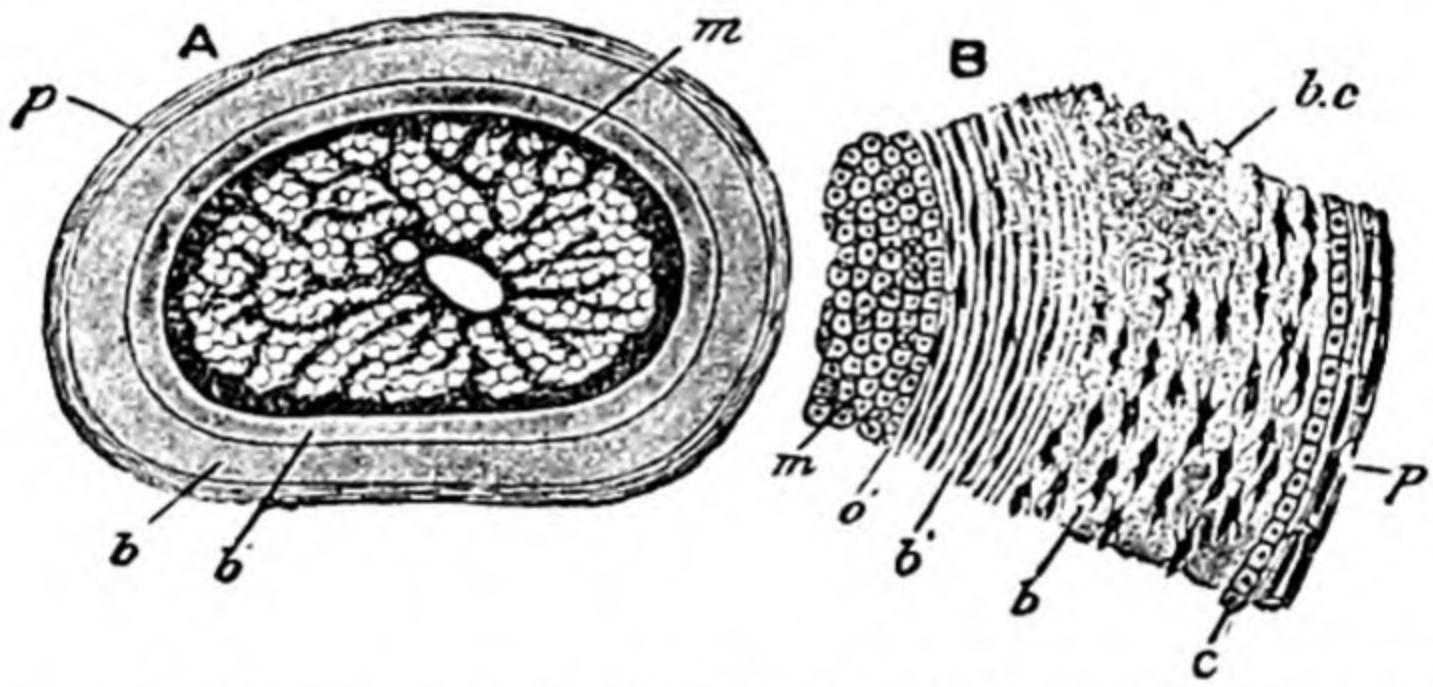


FIG. 39.—A, transverse section of decalcified Frog's femur under a low power. (× 30.) B, portion of the same under a high power. (× about 150.)
b. outer, and *b'*, inner layer of bone; *b. c*. bone-cells; *m*. marrow; *o*. layer of osteoblasts in connection with periosteum; *o'*. layer of osteoblasts in connection with marrow; *p*. periosteum. (After Howes.)

the lamellæ are cell-spaces, corresponding with the lacunæ of the dried bone, and each containing a *bone-cell* (*b. c*), which sends off delicate branched processes of its protoplasm into the canaliculi. Thus the bone, like connective-tissue and cartilage, consists of cells with an intercellular substance: the latter is in the form of concentric layers and is impregnated with lime-salts.

The long bones of the frog grow in two directions. Between the periosteum and the bone is a layer of cells, the *osteoblasts* (*o*), by which new lamellæ of bone are

formed on the outside of those already existing: thus the outer layer of bone (*b*) grows from within outwards. Between the marrow and the inner surface of the bone is another layer of osteoblasts (*o'*) which forms new lamellæ on the inner side of the existing bone, so that the inner layer (*b'*) grows from without inwards.

A transverse section of human bone or that of another Mammal (Fig. 40) shows a different sort of arrangement of the lamellæ. Near the surface, *i.e.*, just underneath the periosteum, the lamellæ are arranged parallel to the surface, but in the interior the lamellæ are arranged in groups of concentric circles called *Haversian systems*, each system consisting of a number of lamellæ arranged concentrically round a central cavity called the *Haversian canal*, through which passes, in the living state, a small artery for supplying nourishment to the system. Between the adjacent Haversian systems there are *interstitial lamellæ*. Such an arrangement has been found in the frog also in

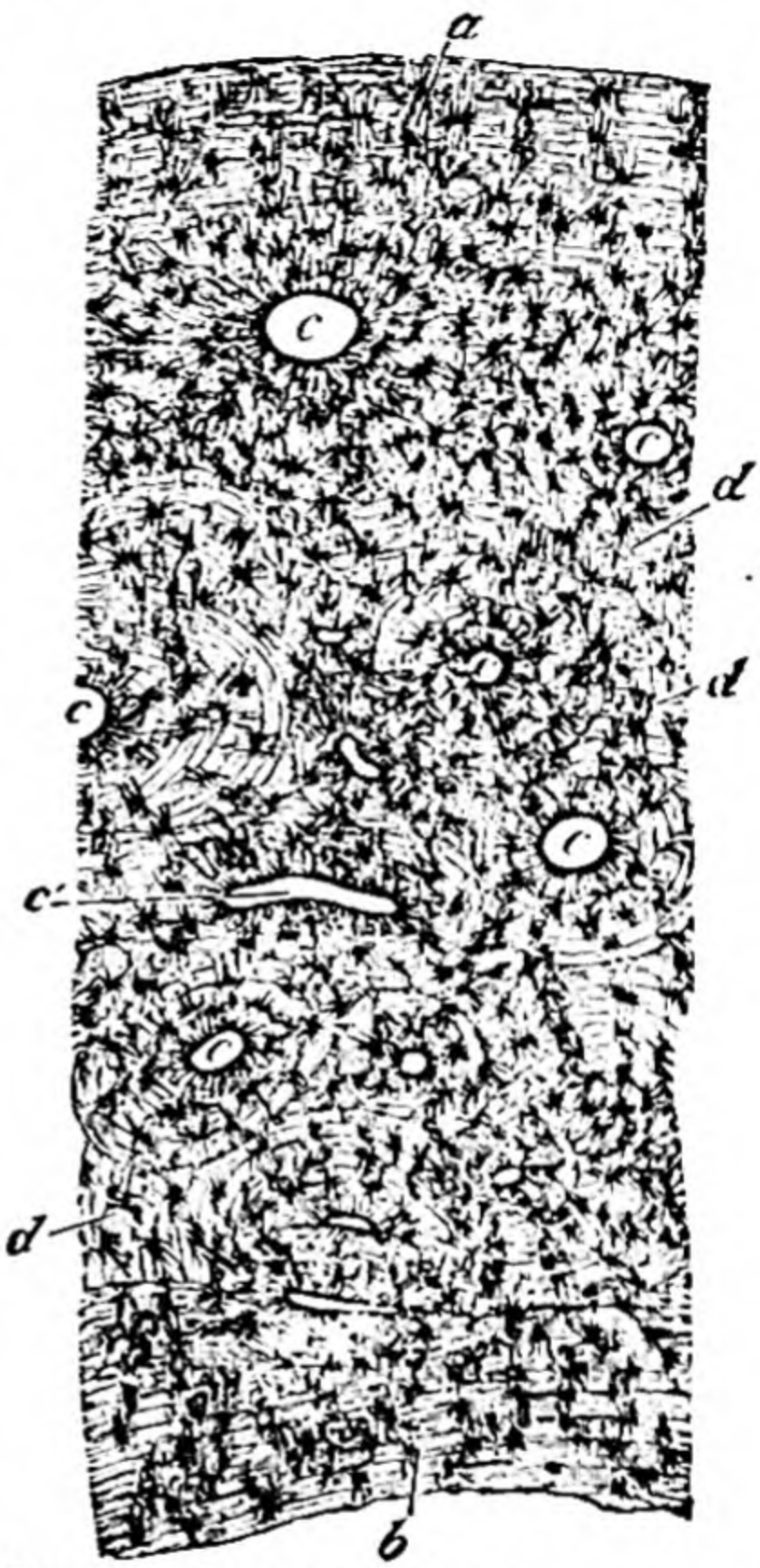


FIG. 40.—Transverse section of dry Human Femur, under a low power.
a. lamellæ of bone parallel or concentric with the external surface; *b*. lamellæ concentric with the surface next the marrow; *c*. Haversian canals cut across, with lamellæ arranged round them; *c'*. a canal just dividing into two; *d*. interstitial lamellæ between the Haversian systems. (From Foster and Shore's *Physiology*.)

the region of the bony partition in such compound bones as the radio-ulna or tibio-fibula (Fig. 15, B, D, *p*.).

Summary.—The various *simple tissues* studied in the present chapter consist either entirely of cells, or of cells separated by an intercellular substance. Formed entirely of cells are the various kinds of epithelium—squamous, columnar, and ciliated, and unstriped muscle. In striped muscle the cells have elongated into fibres and their nuclei have multiplied. Of the supporting tissues, consisting characteristically of cells with intercellular substance, connective-tissue has the matrix soft and homogeneous, with fibres imbedded in it; in hyaline cartilage it is structureless and tough, though elastic; and in bone laminated and calcified. In the blood, the plasma may be looked upon as a kind of liquid intercellular substance.

Cells, wherever they occur, have the same essential structure, being formed of cytoplasm and a nucleus. In nearly all cases they increase by binary fission, first the nucleus and then the cytoplasm dividing into two.

The distribution of the various tissues throughout the body is worth noting. Epithelium always bounds a free surface—*e.g.*, that covering the outer surface of the body or lining the inner surface of the alimentary canal. Striped muscle forms the " flesh," unstriped muscle the outer layer of the alimentary canal (p. 64). Bone and cartilage form the framework of the body, while connective-tissue is the packing between the other tissues.

CHAPTER VIII

THE FROG (*continued*): THE MICROSCOPIC EXAMINATION OF THE COMPOUND TISSUES—GLANDS—SECRETION AND ABSORPTION

WITH the exception of the tissues of the nervous system, which will be described in Chapter X, we have now studied the principal simple tissues by the method of *dissociation, i.e.*, by separating their constituent parts. We have now to consider the way in which these tissues are combined in the various organs, and for this purpose must adopt some method of examination by which they are seen in their natural relations.

The method adopted for this purpose is that of *section-cutting*. You know how, by cutting sections, in various directions, of a bit of twig, the arrangement and natural relations of its various parts—wood, bark, and pith—can be ascertained. The same thing applies to the organs of the frog and other animals, but, owing to their soft and non-resistant texture, it is impossible to cut them into sections thin enough for microscopic examination without special preparation. The methods employed are by no means easy for the beginner, especially without verbal instruction and the resources of a biological laboratory; and in the absence of facilities for section cutting, prepared slides may be examined.

The Skin.—A vertical section of the skin, *i.e.*, one taken at right angles to its surface, will be seen to have the following structure.

The skin is clearly divisible into two layers, an outer,

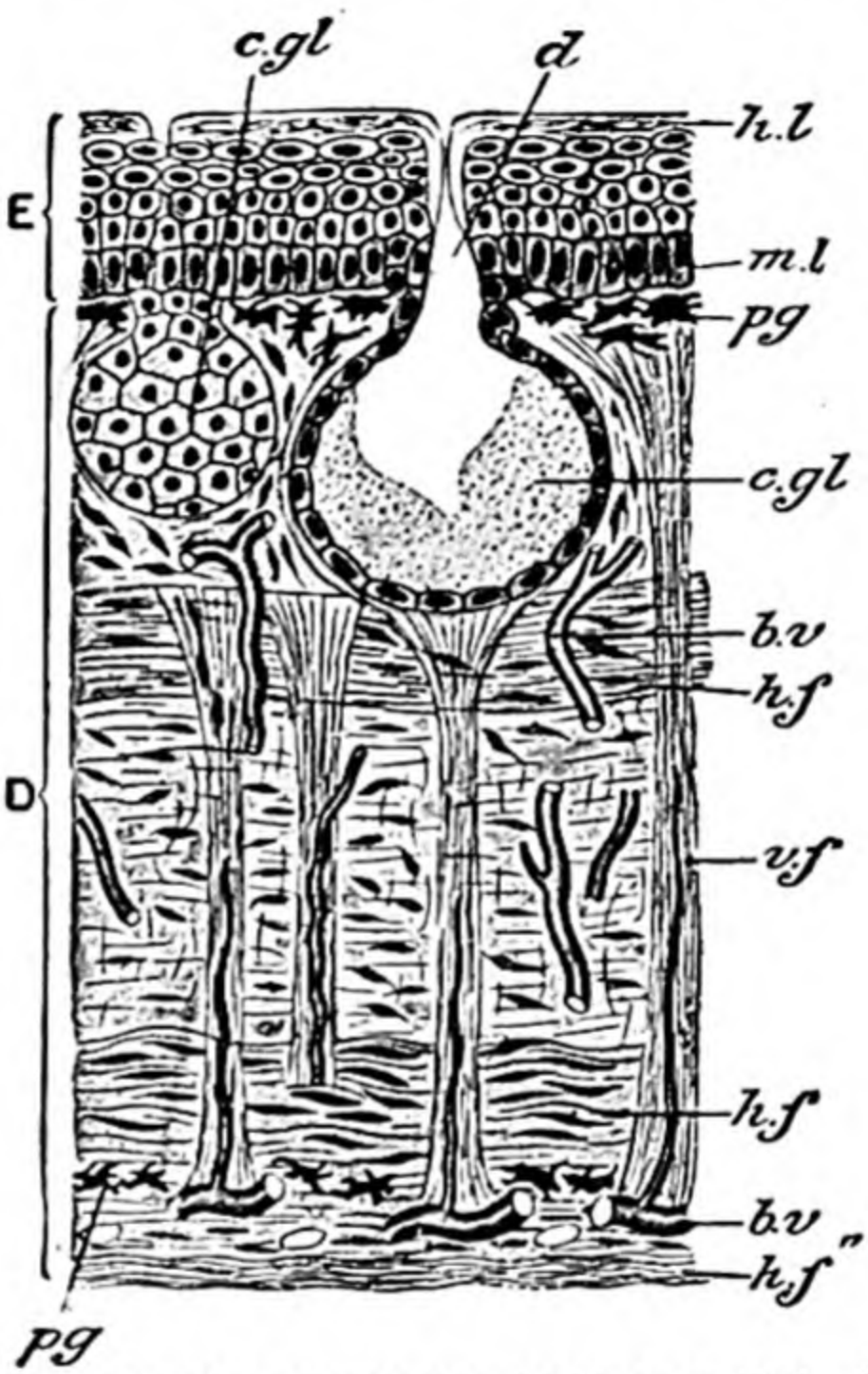


FIG. 41.—Vertical section of the Frog's skin, highly magnified. (× about 200.) D. dermis formed of *hf*, *hf'*, *hf''*. horizontal, and *v. f.* vertical fibres of connective-tissue, and containing *b. v.* blood-vessels, and *pg.* pigment cells. E. epidermis with *m. l.* active or Malpighian layer, and *h. l.* horny layer of epithelial cells; *c. gl.* cutaneous gland in section; *c. gl'.* in surface view; *d.* duct. (After Howes.)

the *epidermis* (Fig. 41, E), and an inner, the *dermis* (D). The epidermis is built up of several layers of epithelial cells. These differ greatly in form according to their position, those in the lower or internal layer (*m. l*) being columnar, while those in the upper or external layer (*h. l*)

are squamous, and have their protoplasm converted into horny matter so as to furnish a comparatively hard and insensitive covering to the body.

The horny layer is cast off periodically in shreds, and to make up for this, the cells of the inner, or deeper layer multiply by binary fission, the increase in their number necessarily resulting in a pushing upwards of the superjacent layers. There is thus a constant travelling of cells from the inner to the outer surface of the epidermis : as they pass towards the outer surface they become more and more flattened, and at last squamous and horny. The whole process takes place in such a way that the multiplication of the columnar cells in the lower layer is just sufficient to make good the loss of the squamous cells in the superficial layer.

The dermis (D) is formed of connective-tissue, the fibres of which are mostly horizontal (*h. f*, *h. f'*, *h. f''*), or parallel to the surface of the skin, but at intervals are found bands of vertical fibres (*v. f*). The dermis also differs from the epidermis in having an abundant blood-supply (*b. v*), capillaries ramifying through it in all directions. It also contains nerves, the ultimate fibres of which have been traced into the deeper layers of the epidermis. Imbedded in the dermis, especially in its external portion, are irregular cells (*pg*), the protoplasm of which contains pigment, often appearing intensely black. It is to these *pigment-cells* that the coloured patches in the frog's skin are due (Figs. 28 and 31).

In this as well as in the other sections described in the present chapter the structure of the nuclei of the various cells can be more easily made out than in the fresh preparations you have already examined. Each nucleus will be seen to be enclosed by a definite *nuclear membrane*, and to contain in its interior a number of

minute bodies, which take up the stain more deeply than the rest of the nucleus. One or more of these bodies may correspond to the nucleoli already seen (p. 103), but many of them are of a different nature and can often be seen to form a network : the material of which these are composed is known as *chromatin*, and is surrounded by a semi-fluid substance forming the groundwork of the nucleus.

Cutaneous Glands—Secretion.—In the superficial part of the dermis are seen numerous rounded spaces (Fig. 41, *c. gl*, *c. gl'*), each of which can be proved, by taking sections in various directions, to be a nearly globular cavity, from which a narrow canal (*d*), like the neck of a flask, passes through the epidermis to open on the external surface. Both the body and the neck of the flask are lined with epithelium, the cells lining the body being nearly cubical, those of the neck squamous.

These structures are called *cutaneous glands* : they perform the function of manufacturing the slimy fluid which, as we have seen, is constantly exuding on the surface of the skin. The epithelial cells of the gland have the power of forming minute droplets of the fluid out of the materials supplied to them by the blood : the droplets escape from the cells and accumulate in the interior of the gland, whence the fluid is finally discharged by the duct.

The cells lining the duct are continuous on the one hand with those of the gland, and on the other with those of the epidermis. The whole gland with its duct is to be looked upon as a depression of the skin, lined by pushed-in epidermal cells.

Epithelial cells having the power of manufacturing and discharging a specific substance are called *gland-cells*, and the process of manufacture is known as *secretion*.

We have already met with isolated gland-cells in the case of the goblet-cells of the intestine (p. 103), which secrete mucus; but commonly, as in the present instance, gland-cells are aggregated into a definite organ called a *gland*.

The Intestine.—A transverse section of the intestine shows also a very definite and characteristic combination

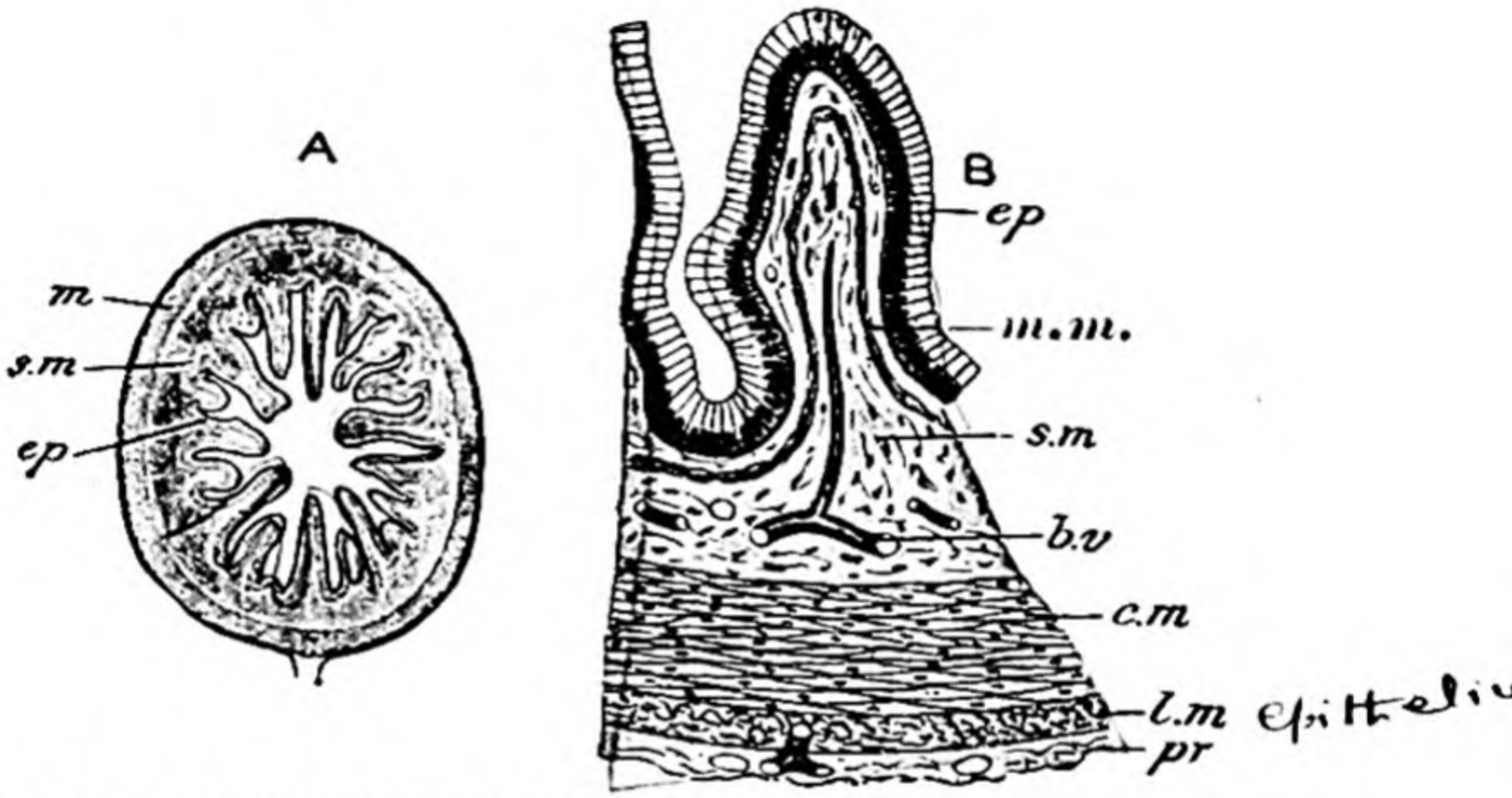


FIG. 42.—A, transverse section of Frog's ileum (× 25); B, small portion of the same highly magnified. (× about 125.)
b. v. blood-vessel; *c. m.* circular layer of muscle-fibres; *ep.* epithelium; *l. m.* longitudinal layer of muscle-fibres; *m. m.* muscularis mucosæ; *pr.* peritoneum; *m.* muscular layer; *s. m.* submucosa. (After Howes.)

of simple tissues. The mucous membrane, like the skin, is composed of two layers, an epithelial layer (Fig. 42, *ep*), corresponding to the epidermis, and a connective-tissue layer (*s. m*), corresponding to the dermis, its deeper part being called the *submucosa* (*see* p. 64). The epithelium consists of a single layer of cells only (B, *ep*), all columnar, and with their long axes at right angles to the elevations into which, as we have seen (p. 65), the mucous membrane is thrown. Amongst

the ordinary epithelial cells numerous mucus-secreting goblet-cells will be recognised. The submucosa, like the dermis, contains blood-vessels, lymphatics, and nerves.

The muscular layer (A, *m*) is also divisible into two: an outer layer of *longitudinal fibres* (B, *l. m*), running parallel with the long axis of the tube, and an inner, much thicker layer of *circular fibres* (*c. m*) which encircle it, and consequently lie at right angles to the longitudinal fibres. Thus in a transverse section, such as Fig. 42, the fibres of the circular layer are cut longitudinally, those of the longitudinal layer transversely, while the opposite would be the case in a longitudinal section.

The peritoneum (*pr*), which, as we have seen (p. 24), forms an outer covering to the intestine, is formed of a thin inner layer of connective-tissue and an outer of squamous epithelium.

The Stomach.—Transverse sections of the stomach (Fig. 43) show it to differ from the intestine not only in the much greater thickness of all its layers, but also in the fact that the epithelium, instead of simply forming an even layer over the ridges of mucous membrane, is sunk into the mucous membrane in the form of simple or branched tubes, the *gastric glands* (*g. gl*). These differ from the cutaneous glands in being not flask-shaped but test-tube-shaped, each being a long, narrow tube, with an extremely small cavity (B and C, *c*). They are lined by a single layer of gland-cells, and open by minute apertures (*m*) on the surface of the mucous membrane.

The cells of the gastric glands have the power of forming, out of the materials supplied to them by the blood, the gastric juice, by which, as we have learnt (p. 70), proteins are digested. Thus, while the raw

material supplied to both cutaneous and gastric glands is the same, the manufactured article is entirely different in the two cases. Each kind of gland-cell has the faculty of picking and choosing, the material supplied

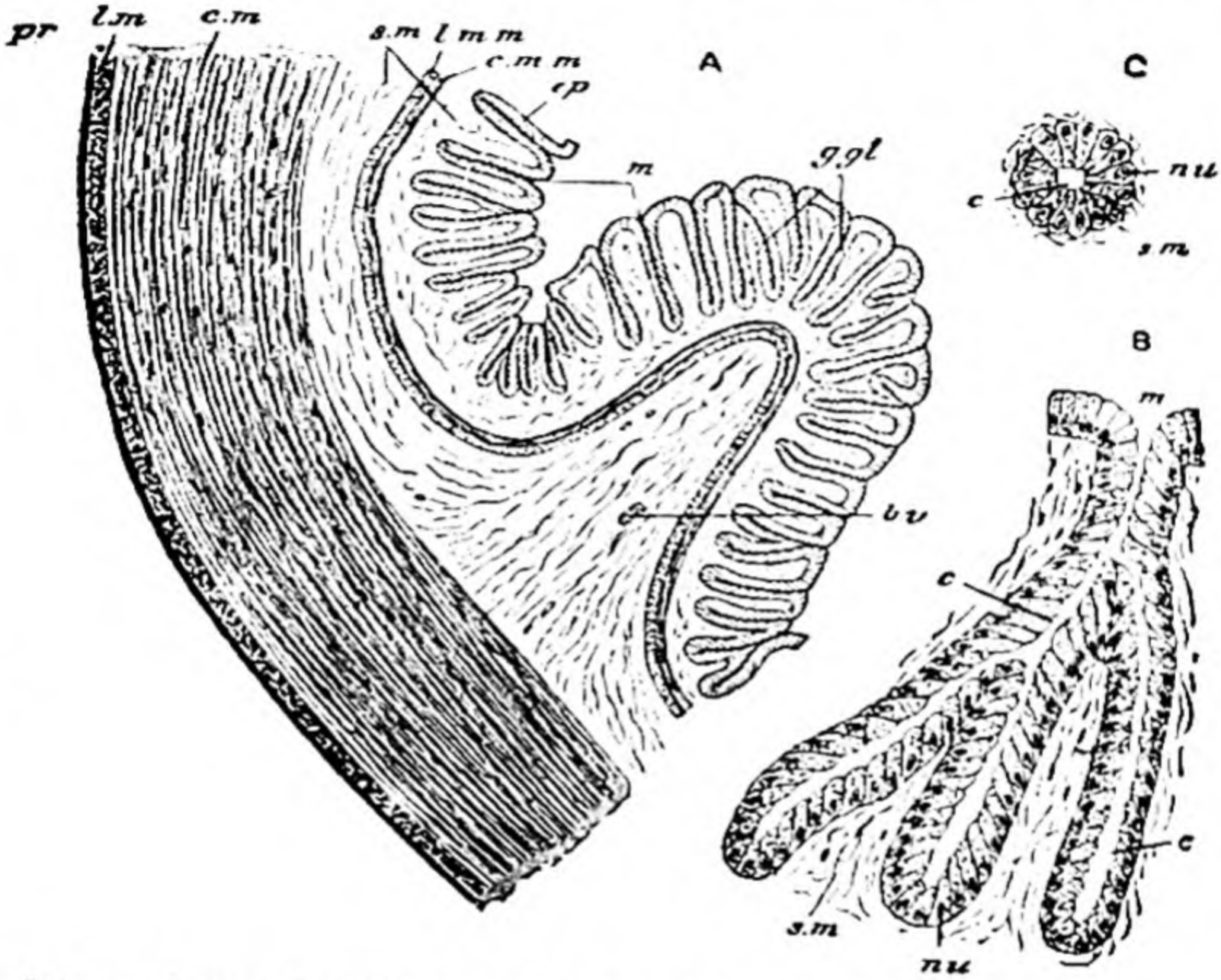


FIG. 43.—A, part of a transverse section of the Frog's stomach (× about 50); B, one of the gastric glands in longitudinal section (× about 300); C, transverse section of a gastric gland.

b. v. blood-vessel; *c.* cavity of gastric gland; *c. m.* circular muscles; *c. m. m.* circular layer of muscularis mucosæ; *ep.* epithelium; *g. gl.* gastric glands; *l. m.* longitudinal muscles; *l. m. m.* longitudinal layer of muscularis mucosæ; *m.* mouth of gastric gland; *nu.* nucleus; *pr.* peritoneum; *s. m.* submucosa.

being worked up in the one case into the cutaneous secretion, in the other into gastric juice.

The submucosa of the stomach is traversed by a narrow band of unstriped muscle, the *muscularis mucosæ*, formed, like the main muscular layer, of an

outer layer of longitudinal (*l. m. m*) and an inner of circular (*c. m. m*) fibres.[1]

The Pancreas.—Sections of this gland (Fig. 44) show it to be made up of microscopic masses or *lobules* (*l*), each of which consists of a cluster of gland-cells enclosing a very narrow central space. The cavities of adjacent lobules communicate with one another and open into tubes or *ducts* (*d*) lined with epithelium, which join with one another and finally discharge into

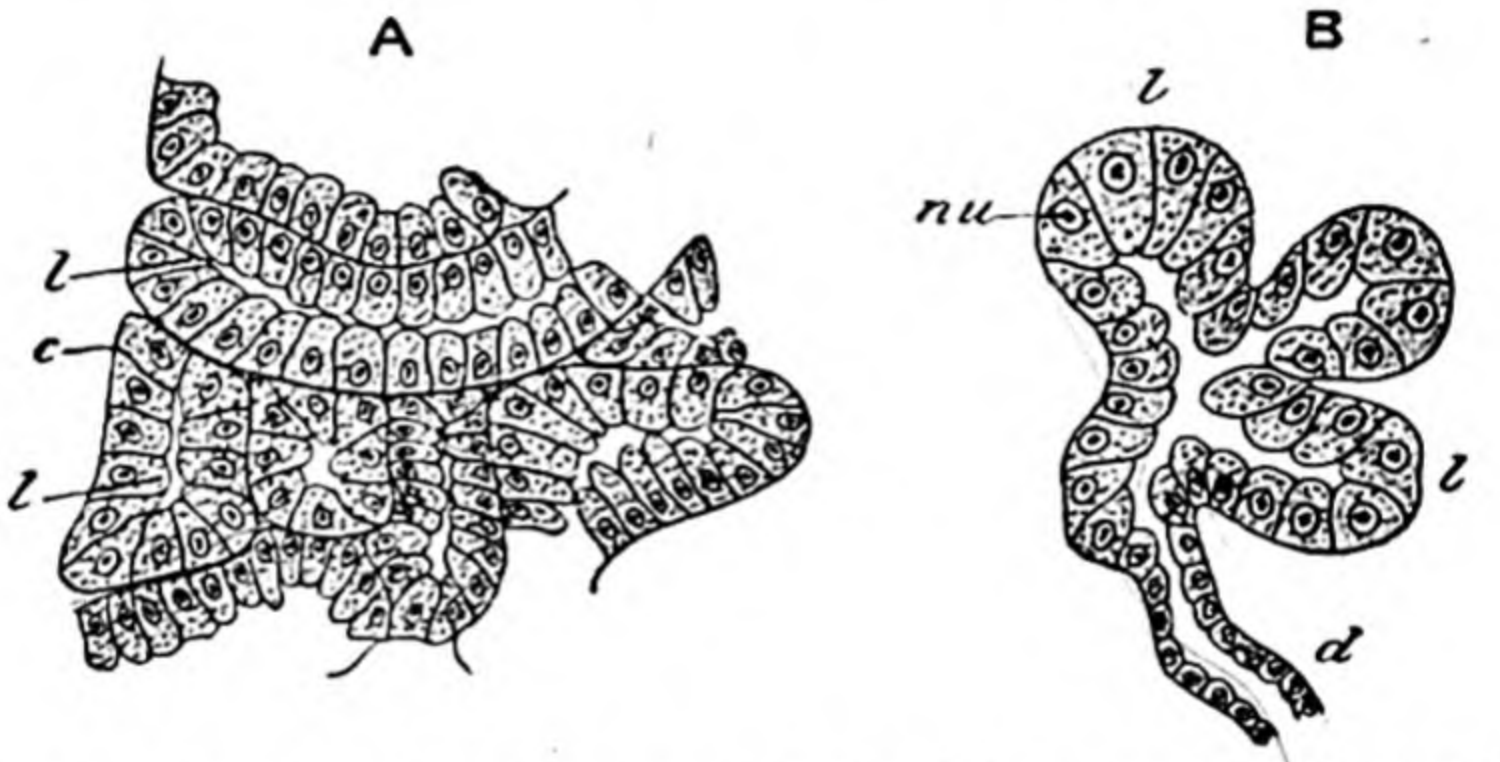


FIG. 44.—A, small portion of a section of the Frog's pancreas (× about 300); B, diagram showing the connection between the lobules and ducts.
c. connective-tissue covering the lobules; *d.* duct; *l.* lobules; *nu.* nucle

the bile-duct as it traverses the pancreas (p. 67). The pancreas is distinguished as *racemose* or grape-bunch gland: the duct is comparable to the branched stalk and the lobules to the grapes.

The Liver.—Sections of the liver show it to be made up of innumerable large, polyhedral cells (Fig. 45, *hp*, *c*), arranged in columns, and bounding extremely fine channels or *bile-passages* (*c. b*, *b. p*). These are found to open into one another, and finally to discharge into

[1] A very thin muscularis mucosæ is also present in the intestine (compare Fig. 42, B).

definite tubes (B, *d*), lined with epithelium. These, in their turn, unite into larger and larger tubes, which form the hepatic ducts and ultimately open into the common bile-duct (p. 67).

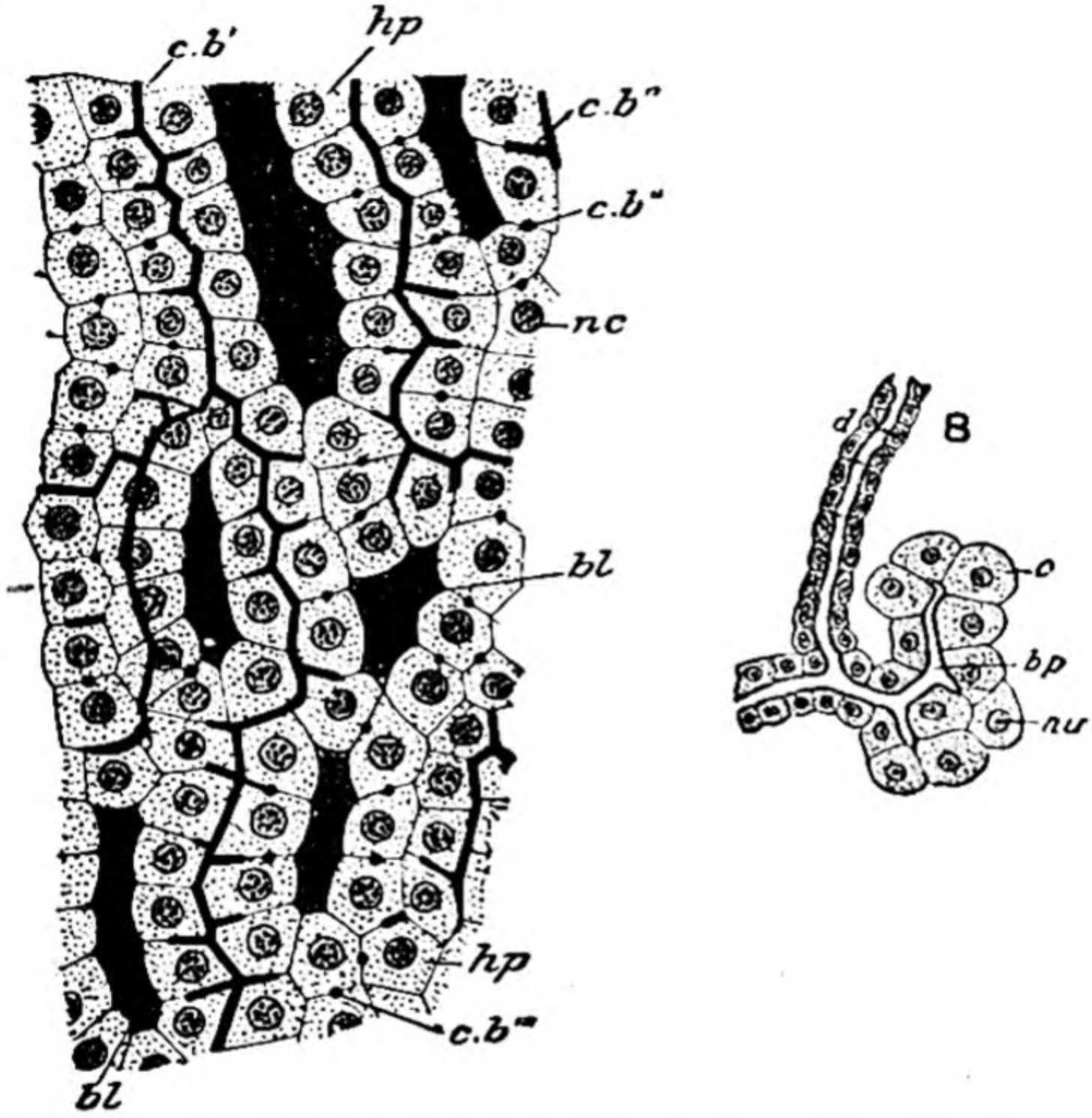


FIG. 45.—A, portion of a section of the Frog's liver (× 350); B, small portion of the same, showing the origin of a bile-duct.
bl. blood-capillaries; *b. p.*, *c. b.*, *c. b'*, *c. b''*, bile-passages; *c. b'''*, the same in transverse section; *c.*, *hp*. liver-cells; *d*. smallest bile-duct; *nc*. *nu*. nuclei.
(A, after Howes; B, after Hoffmann.)

The liver-cells are glandular and secrete the bile, which, as it is formed, exudes into the bile-passages and passes into the hepatic ducts, thence making its way either directly into the intestine or into the gall-bladder

(p. 67). The whole liver, which is the largest gland in the body, is traversed by a complex network of capillaries (*bl*), arising partly from the hepatic artery, partly from the hepatic portal vein; and from the blood thus supplied, the liver-cells obtain the materials necessary to enable them to discharge their function of secreting the bile.

The liver-cells have, however, other functions, one of which is to manufacture a substance called *glycogen*, or animal-starch, out of sugar absorbed in the intestine and brought to the liver by the blood in the portal vein. This is stored up in the cells in the form of minute insoluble granules, the material of which, being afterwards transformed into soluble sugar, gradually passes into the blood and so to the tissues. A good deal of the excess of amino-acids formed by the digestion of proteins, as also those formed by the oxidation of the proteins of the tissues of the body and carried to the liver in the blood-stream, are changed into urea by that organ.

Connection of the foregoing facts with the Physiology of Nutrition.—You will now be able to understand more clearly the various processes connected with the nutrition of the frog, hitherto studied without the aid of histology.

When the food enters the alimentary canal the various gland-cells are stimulated into activity, and the gastric juice, bile, and pancreatic juice are poured out and mingled with the food, which is digested in the manner already described. The soluble products of digestion—peptones, amino-acids, sugars, salts, fatty acids, and glycerine—diffuse through the epithelium of the alimentary canal into the blood-capillaries of the underlying submucosa, and the blood, now loaded with nutriment, is carried by the portal vein to the liver and thence by the hepatic and postcaval veins to the heart (see Fig. 27).

At the same time the fats make their way into the lymph-capillaries and are finally pumped, by the lymph-hearts, into the veins. Thus the products of digestion all find their way ultimately into the blood, and are distributed, through the circulatory mechanism, to all parts of the body.

CHAPTER IX

THE FROG (*continued*) : RESPIRATION AND EXCRETION

IN the fifth chapter it was pointed out that a continual waste of substance goes on in the frog's body, the lost material taking the form of three chief waste-products or *products of excretion*, water, carbon dioxide, and urea. It was further stated that these substances are got rid of by means of the lungs, the kidneys, and the skin.

The Organs of Respiration.—At their anterior ends the two lungs open into a small, thin-walled chamber (Fig. 46, *l. tr. c*), which as it corresponds both with the larynx or organ of voice, and the trachea or windpipe in ourselves, is called the *laryngo-tracheal chamber* : it communicates with the pharynx through the glottis (*gl.*). The walls of the chamber and the edges of the glottis are supported by cartilages (*ar.*).

The structure of the lung is best made out by distending it with air, and then placing it in formaline or spirit until thoroughly hardened : its walls contain so much elastic tissue that if cut when fresh it contracts immensely, and its structure is then difficult to see. The inner surface of the lung is raised up into a complex network of ridges (A, *r. lng.*), which project into the interior and produce the appearance of an irregular honeycomb. All these ridges are abundantly supplied

with blood-vessels fed by the pulmonary artery, the blood being carried away by the pulmonary vein.

The main substance of the lung is made of connective-tissue containing elastic fibres and unstriped muscle, and traversed by a network of capillaries. Its cavity is lined by a layer of pavement epithelium, and its outer surface is covered with peritoneum.

It must be remembered that in the frog the skin also acts as an important organ of respiration. Whenever a frog is under the water, respiration is carried on entirely by the skin.

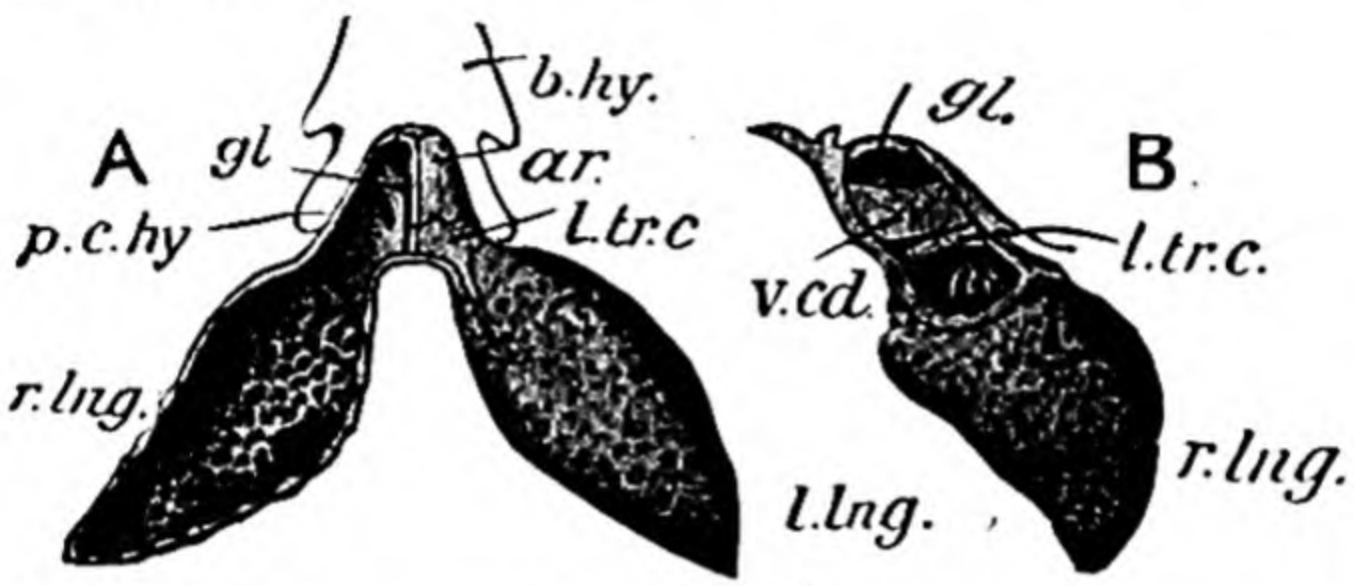


FIG. 46.—A, the respiratory organs of the Frog from the ventral aspect; B, the laryngo-tracheal chamber in longitudinal section, with the right lung. (× 1½.) *ar.* the arytenoid, or principal cartilage of the larynx; *b. hy.* body of hyoid; *gl.* glottis; *l. lng.* left lung; *l. tr. c.* laryngo-tracheal chamber; *p. c. hy.* posterior horn of hyoid; *r. lng.* right lung, laid open in A to show its internal surface; *v. cd.* vocal cord. (After Howes.)

Respiratory Movements.—In breathing, the frog depresses the floor of the buccal cavity (Fig. 47, A), and the mouth being kept shut, air is drawn in through the nostrils. The floor of the mouth is then raised (B) by muscles attached to the hyoid. At the same time the anterior end of the lower jaw presses upon the movable premaxillæ (*pmx*), the upward processes of which (p. 40, Figs. 10 and 11, *pm*) act upon certain cartilages in connection with the external nostrils in such a way as to produce closure of these apertures (Fig. 47, B). The

gullet (*gul*) is so contracted, except during the act of swallowing, as to be practically closed. Thus when the floor of the mouth is raised, the air contained in it can escape in one way only, viz., through the glottis into the lungs.

Thus *inspiration*, or breathing-in, is produced by the

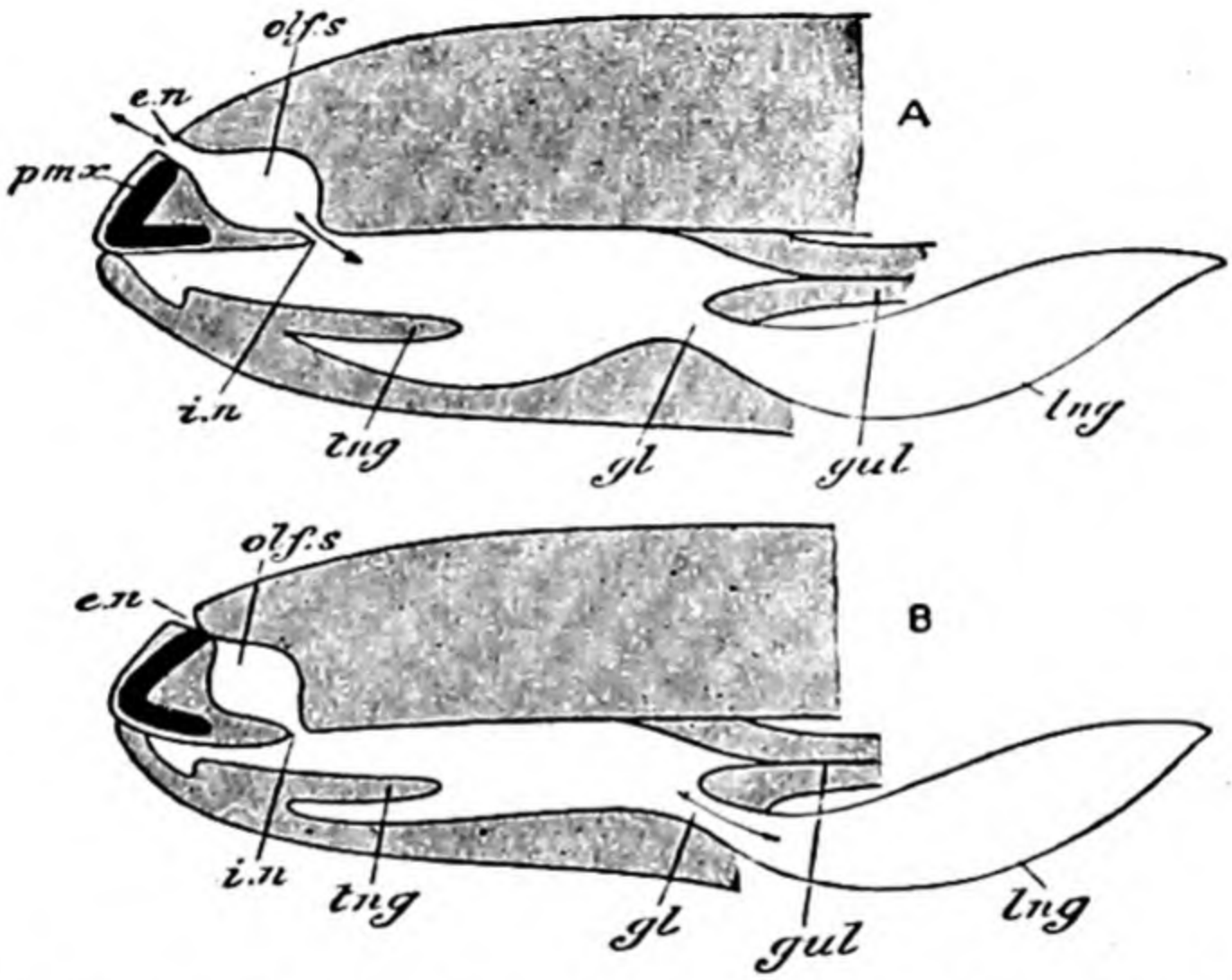


FIG. 47.—Diagrams illustrating the respiratory movements of the Frog (× 2). In A the floor of the mouth is depressed and air is being drawn in through the nostrils; in B the floor of the mouth is raised, the nostrils are closed, and air is being forced into the lungs.

e. n. external nostril; *gl.* glottis; *gul.* gullet; *i. n.* internal nostril; *lng.* lung; *olf. s.* olfactory sac; *pmx.* premaxilla; *tng.* tongue.

buccal cavity acting as a force-pump; the lowering of its floor draws in air through the nostrils, the raising of its floor forces the imprisoned air into the lungs. *Expiration*, or breathing-out, is due to a contraction of the elastic lungs, accompanied by a slight lowering of the tip of the lower jaw: the latter movement

releases the premaxillæ and thus opens the external nostrils.

Respiration.—By the alternate movements of inspiration and expiration, fresh air passes into the lungs at regular intervals, while part of the air already contained in them is expelled. Now we saw, when studying the blood (p. 75), that dark purple blood drawn from a vein becomes bright scarlet when exposed to air, and we subsequently learnt (p. 100) that this change is due to the absorption of oxygen by the red corpuscles.

The blood brought to the lungs by the pulmonary artery is, as we have seen (p. 90), non-aërated, being the impure blood returned by the three caval veins to the right auricle. When this blood is pumped into the capillaries of the lungs it is separated from the air contained in those organs only by the extremely thin walls of the capillaries themselves and the equally delicate pavement epithelium lining the lungs (p. 125, and Fig. 27, *Cp. lng*, *Ep. lng*). Under these circumstances an interchange of gases takes place between the air in the lungs and the gases dissolved in the blood: the hæmoglobin of the red corpuscles absorbs oxygen, and the carbon dioxide in the blood, derived from the waste of the tissue, is given off into the cavities of the lungs. The blood in the pulmonary capillaries thus becomes aërated and is returned as red blood to the left auricle: at the same time it loses carbon dioxide, together with a certain amount of water, and these waste substances are expelled from the body with the expired air.

Voice.—It was mentioned above (p. 124) that the glottis and laryngo-tracheal chamber are supported by cartilages. The largest of these are a pair of semilunar *arytenoid cartilages* (Fig. 46, *ar*), which bound the glottis to right and left. The mucous membrane on the inner or adjacent faces of the arytenoids is raised into a

pair—right and left—of horizontal folds, the *vocal cords* (*v. cd*). By means of muscles these folds can be stretched and relaxed, and can be brought into either a parallel or a divergent position. When they are parallel the air, passing to and from the lungs, sets their edges in vibration and gives rise to the characteristic croak, the pitch of which can be slightly altered by stretching or relaxing the cords.

Structure of the Kidneys.—The form and situation of the kidneys (Figs. 5, 6, and 8, *kd*) have already been referred to. Each is a flattened organ of a deep reddish-

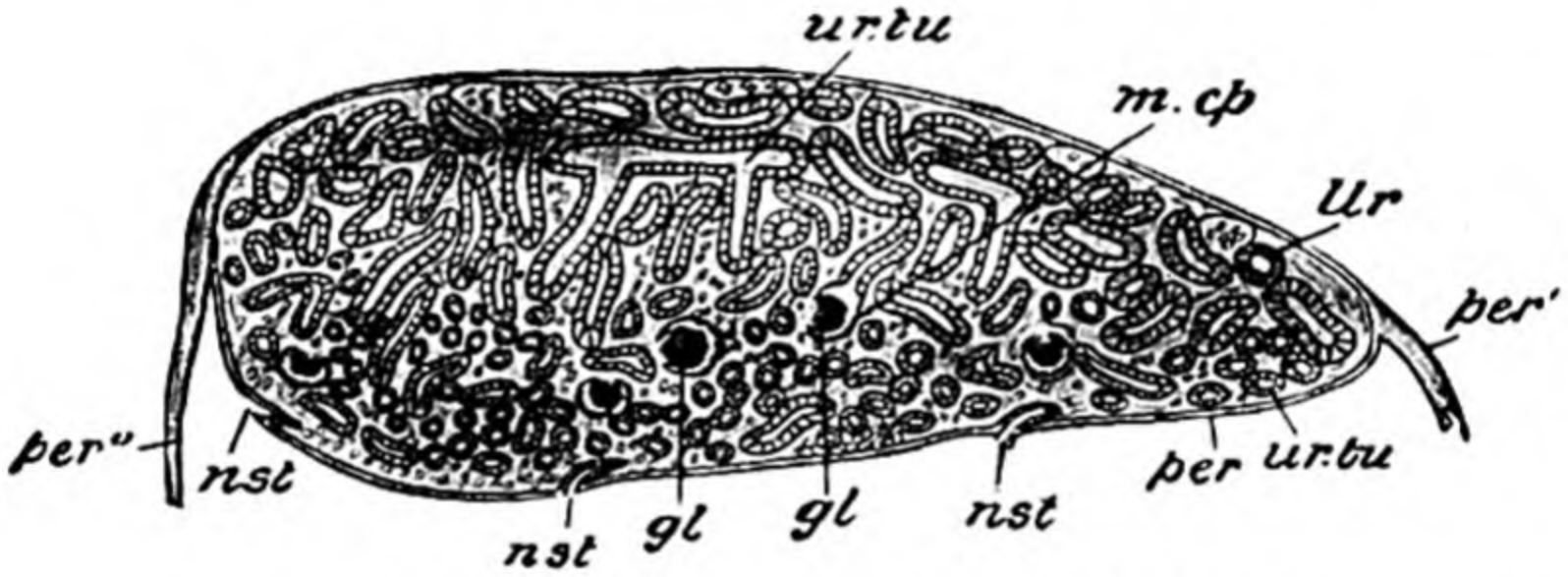


FIG. 48.—Transverse section of Frog's kidney. (× 45.
gl. glomerulus; *m. cp.* Malpighian capsule; *nst.* peritoneal funnels; *per.* peritoneum covering ventral face of kidney; *per'.* fold of peritoneum supporting its outer border; *per''.* fold supporting its inner border; *Ur.* ureter; *ur. tu.* urinary tubules. (After Marshall and Bles.)

brown colour, its inner edge nearly straight but for one or two notches, its outer edge curved. Its ventral face is covered by peritoneum (Fig. 48, *per*), continued on the one hand into the parietal layer (Fig. 6, *p. per*) of that membrane, on the other into the mesentery (*mes*); its dorsal face is bathed by the lymph of the sub-vertebral sinus (*sv. ly. s*). From the posterior end of its outer edge a delicate tube, the ureter (Figs. 5, 8, and 25, *ur*), passes backwards and opens into the dorsal wall of the cloaca. On its ventral face is a singular yellow stripe, the *adrenal*

body, which is an important ductless gland (Fig. 8, between the lines from *kd* and *ts*, and 25, *ad.*).

A thin section shows the whole kidney to be made up of a tangled mass of microscopic tubes (Fig. 48, *ur. tu*), so twisted together that any section cuts them in various planes, some transversely, when they appear as circles, others longitudinally or obliquely. Amongst these *urinary tubules* or *nephridia*, as they may be called, are seen globular sacs, the *Malpighian capsules* (*m c.p*), each having in its interior a little rounded bunch, known as the *glomerulus* (*gl*). Very accurate examination of numerous sections, as well as of teased-out specimens, shows that each Malpighian capsule (Fig. 49, *m. cp*) is connected with a urinary tubule (*ur. tu*), to which it forms a blind, bulb-like end. The tubule itself winds through the substance of the kidney, is joined by

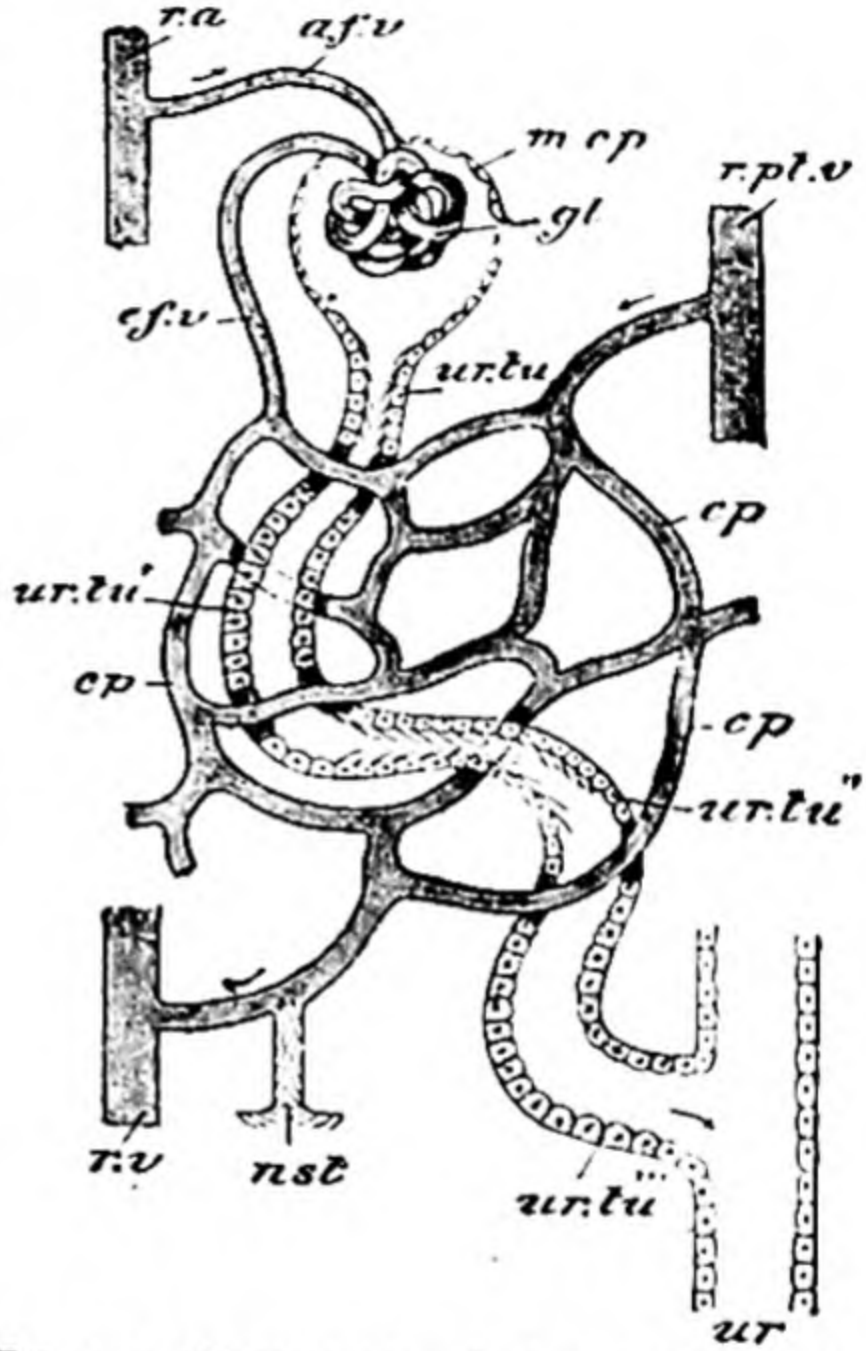


FIG. 49.—Diagram of a single urinary tubule with its blood-vessels, to illustrate the structure of the Frog's kidney.

af. v. afferent vessel of glomerulus; *cp.* capillary network of kidney; *ef. v.* efferent vessel of glomerulus; *gl.* glomerulus; *m. cp.* Malpighian capsule, showing epithelium (which in reality also covers the glomerulus); *nst.* peritoneal funnel; *r. a.* renal artery; *r. pl. v.* renal portal vein; *r. v.* renal vein; *ur.* ureter; *ur. tu, ur. tu', ur. tu'', ur. tu'''*, different portions of urinary tubule, showing epithelium and cilia.

other tubules, and finally discharges into the ureter (*ur*). The tubules are lined with somewhat cubical cells of glandular epithelium, which, in some parts (*ur. tu*, *ur. tu''*), are ciliated. The Malpighian capsules are lined with flattened cells of pavement epithelium.

The arrangement of the blood-vessels is peculiar. Like other organs, the kidney is permeated by a network of capillaries (*cp*) which form a close mesh between the urinary tubules, so that the cavity of the tubule is separated from the blood only by the thickness of the gland-cells and of the capillary wall. The capillary network is supplied partly by the renal arteries (*r. a*), partly by the renal portal vein (*r. pt. v*), and is drained by the renal veins (*r. v*). It is in the behaviour of the renal arteries that the chief peculiarity of the kidney-circulation lies. On entering the kidneys they break up into smaller and smaller arteries, but each of the ultimate branches (*af. v*), instead of discharging into the general capillary network, passes to a Malpighian capsule, in the interior of which it breaks up into a little bunch of coiled capillaries, the *glomerulus* (*gl*). From this the blood is carried off by a minute vessel (*ef. v*) by which it is poured into the general capillary network and finally discharged into the renal vein (*r. v*).

Renal Excretion.—While circulating through the glomerulus, water and certain soluble matters are separated from the blood and make their way into the Malpighian capsule and thence into the urinary tubule. As the blood circulates through the general capillary network, the gland-cells of the tubules excrete, out of the materials brought to them by the blood, the nitrogenous waste matter *urea*, in the formation of which the liver plays an important part (p. 122); it is discharged from the cells into the cavity of the tubule, where it is dissolved in the water separated out of the glomerulus.

In this way the *urine* is formed. Accumulating in the tubules, it makes its way into the ureter and thence drop by drop into the cloaca, whence it is either expelled at once, or stored for a time in the bladder.

Note that the formation of urine is a process of secretion of a similar nature to the secretion of gastric juice, bile, &c. The fluid secreted is, however, of no further use to the animal, and would, in fact, act as a virulent poison if retained in the system. It is therefore got rid of as soon as possible. Secretions of this kind, consisting not of useful but of harmful or waste matters, are distinguished as *excretions*.

Bile is also in part an excretion as it contains pigments due to the disintegration of hæmoglobin, and thus by its means the effete colouring-matters of the blood are passed into the intestine and got rid of.

Pulmonary and Cutaneous Excretion.—The lungs, besides being organs of respiration, take their share in excretion, since they get rid of the important waste product, carbon dioxide, together with a considerable quantity of water. Similar functions are discharged by the skin, which is also an organ both of respiration and of excretion. Interchange of gases takes place between the outer air and the blood in the capillaries of the dermis: the carbon dioxide of the non-aërated blood brought to the skin by the cutaneous artery (p. 90 and Fig. 27) is exchanged for oxygen, and the blood, in the aërated condition, is returned by the musculo-cutaneous vein to the heart. Moreover, the cells of the cutaneous glands separate water and other constituents from the blood, and the fluid thus formed is poured out on the surface of the body. Here it serves to keep the skin moist, and is finally lost, either by evaporation or by mingling with the water in which the frog is immersed. The

cutaneous secretion has also poisonous properties, and so probably serves as a defence against some of the animal's enemies.

Summary of the Processes of Metabolism.—We are now in a position to understand the general features of the whole complicated series of processes which have to do with the nutrition and growth as also the breaking down of the tissues of the frog, which are collectively spoken of as *metabolism*. These processes are illustrated in the diagram (Fig. 27, p. 88), which should be constantly consulted in connection with the following summary.

All parts of the body are placed in communication with one another by means of the blood-vessels, through which a constant stream of blood is flowing in a definite direction.

In all parts, waste of substance (*destructive metabolism* or *katabolism*) is continually going on, and the waste products—water, carbon dioxide, and some nitrogenous substances which ultimately take the form of urea—are passed either directly into the blood, or first into the lymph and thence into the blood.

At the same time the cells withdraw nutrient materials from the blood, and *assimilate* them, *i.e.*, form new living substance, whereby the waste is made good, and the tissues adequately nourished (*constructive metabolism* or *anabolism*). Oxygen is also withdrawn from the blood; like the air supplied to a fire, it is essential to the oxidation or low-temperature combustion with which the waste of tissues is associated. By the withdrawal of its oxygen the hæmoglobin of the blood alters its colour from scarlet to purple.

Thus the blood as it passes through the body is constantly being impoverished by the withdrawal of nutrient matters and of oxygen, and as constantly being fouled by the discharge into it of waste products. It

reaches the capillaries of an organ as bright red, aërated blood, and leaves it as purple, non-aërated blood.

These changes, by which the blood loses nutrient matters and oxygen and gains waste products, take place all over the body. The converse processes by which nutrient matters and oxygen are absorbed and waste products got rid of are carried on in certain definite portions of the circulatory system.

In the walls of the alimentary canal (Fig. 27, *Ent. C*), the products of digestion pass into the blood (*Cp. Ent. C*), or in the case of fats, first into the lacteals and ultimately into the blood. In this way the due proportion of nitrogenous and other food-materials is kept up.

In passing through the capillaries of the lungs (*Cp. Lng*), carbon dioxide is exchanged for oxygen and a certain amount of water is given off. In the capillaries of the skin (*Cp. Sk*), a large quantity of water and smaller proportions of other waste matters are got rid of. In the kidneys (*Cp. Kd*), a considerable quantity of water, together with the bulk of the urea, are removed from the blood and finally expelled from the body.

Note that all these changes are produced by the special activity of particular groups of epithelial cells, which, however alike they may be in general appearance and structure, have a marvellous selective faculty peculiar to themselves. Like all other parts of the body, they are constantly undergoing the usual processes of waste and repair, withdrawing nutrient matters and oxygen from the blood, and passing waste matters into it. But, in addition to the ordinary processes of nutrition, each particular group of cells has the power of withdrawing a specific substance from the blood or of passing substances into it. Thus the epithelial cells of the alimentary canal (*Ep. Ent*) pass in digested food,

those of the skin (*Ep. Sk*) and Malpighian capsules (*Mlp. Cp*) withdraw water, those of the urinary tubules (*Ep. Ur. T*) urea, and so on. Similarly, the various gland-cells, such as those of the liver (*Lvr. C*), pancreas (*Pn. C*), gastric and cutaneous (*Cu. Gl*) glands, withdraw specific substances, or *secretions*, which are discharged on the free surface of the epithelium and serve various purposes.

We see that the blood loses—(1), nutrient matters and oxygen all over the body; (2), water in the skin, lungs, and kidneys; (3), carbon dioxide in the lungs and skin; (4), urea, principally in the kidneys; and (5), various substances in the glands. It gains (1), waste products all over the body; (2), nutrient matters in the alimentary canal; (3), liver-sugar (p. 122) in the liver; (4), oxygen in the lungs and skin. It is therefore richest in oxygen and poorest in carbon dioxide as it leaves the lungs and skin, *i.e.*, in the pulmonary and musculo-cutaneous veins; richest in nutriment as it leaves the alimentary canal, *i.e.*, in the portal vein; poorest in urea as it leaves the kidneys, *i.e.*, in the renal veins; poorest in water as it leaves the skin and kidneys, *i.e.*, in the cutaneous and renal veins.

In this way a single closed system of pipes not only supplies all parts of the body with everything necessary for their sustenance, but serves also as a drainage system to carry away their various waste products.

Notice that we must distinguish between the nutrition, respiration, and excretion of the frog as a whole, and of its various parts. Every one of the thousands of cells, fibres, &c., in the entire body is nourished, breathes, and excretes, taking its nourishment and oxygen directly from the blood, and discharging its waste products into it. What are called the *organs* of nutrition and respiration are special portions of the body set

apart for taking in fresh supplies of food or of oxygen for the organism as a whole, such supplies being finally distributed by the blood-system. Similarly, what are called the organs of excretion are special portions of the body by which the waste products, collected by the blood from all parts of the organism, are finally discharged.

Evolution of Heat.—The oxidation of the tissues, like that of coal or wood in a fire, is accompanied by a rise in temperature. But in the frog, as in other cold-blooded animals, the evolution of heat is never sufficient to raise the temperature of the body more than very slightly above that of the surrounding medium. In warm-blooded animals, such as ourselves, the temperature is regulated, according to the season, by a greater or less evaporation of water from the surface of the body. In the frog this is not the case : the temperature of the animal is always nearly the same as that of the air or water in which it lives, and hence the frosts of winter would be fatal to it but for the habit of hibernation (p. 9).

Death and Decomposition.—The decomposition undergone by a dead frog (p. 12) may be looked upon as an excessive process of waste unaccompanied by repair. Owing to the action of certain microscopic plants known as *Bacteria*, the proteins undergo oxidation, amongst the principal products of which are water, carbon dioxide, ammonia, and certain gases of evil odour, such as sulphuretted hydrogen and ammonium sulphide. Most of the gases escape into the air, while the ammonia is finally converted into nitrous and nitric acids. These, combining with certain substances in the soil, give rise to salts called nitrites and nitrates, which furnish one of the chief sources of the food of plants.

CHAPTER X

THE FROG (*continued*): THE NERVOUS SYSTEM

In a machine of human construction, such as a steam-engine, the proper working of the whole depends, providing the parts of the machine itself are in good order, upon two things—the stoking or regulation of the fires, and the turning of certain cocks and levers by the engineer. In that very complex machine the frog, we have already studied what corresponds to stoking, viz., feeding and breathing. We must now direct our attention to what may be considered roughly to correspond with the work of the engineer—the means by which the whole complex machinery is kept under control, and its various parts made to work together to a common end.

How does it come about, for instance, that the various digestive glands begin to secrete actively as soon as food is taken into the alimentary canal? How is it that a touch on any part of the body, or even the sight of an enemy, is followed instantaneously by a series of vigorous muscular movements so ordered as to facilitate escape from the source of danger?

In the fourth chapter (p. 59), we got so far as to learn that muscular contractions are induced by *nervous impulses* travelling from the brain or spinal cord, along the

nerves, to the muscles. It may therefore be inferred that the controlling apparatus, by which the functions of the body are regulated, is lodged in either the brain or the spinal cord, or in both.

Divisions of the Nervous System.—The nervous system is divisible into (1) the *central nervous system*, consisting of the brain and spinal cord (Figs. 7 and 8), and (2) the *peripheral nervous system*, consisting of the nerves which pass from the central nervous system to the various parts of the body. The nerves are divisible into (1), *cerebral nerves* (Fig. 55), arising from the brain, (2), *spinal nerves* (Fig. 53), arising from the spinal cord, and (3), *sympathetic nerves* (Fig. 53).

The Spinal Cord.—In form the spinal cord (Figs. 7 and 8, *sp. cd*) is irregularly cylindrical. It is continuous in front with the brain, and tapers off posteriorly into a fine thread-like portion, the *filum terminale* (*f. t*), while opposite the fore-limbs, and again just anteriorly to the filum terminale, it presents an enlargement: these are known respectively as the *brachial* and *sciatic* swellings. Along its dorsal surface runs a delicate longitudinal line, the *dorsal fissure* (Fig. 50, *d. f*), and a distinct groove, the *ventral fissure* (*v. f*), extends along its lower surface.

The cord is covered with a delicate pigmented membrane known as the *pia mater* (*p. m*), and the neural canal in which it lies is lined with a stout, tough membrane, the *dura mater* (Fig. 54, *d. m*). Between the two is a space filled with a lymphatic *arachnoid fluid*, which, like the pericardial fluid, preserves the contained organ from shocks.

Examination of a transverse section of the cord under a lower power will show that the dorsal fissure is an extremely narrow vertical wall formed by an extension inwards of the pia mater. The ventral fissure is a distinct cleft. Thus the two fissures divide the cord

into paired half-cylinders, right and left, joined in the middle by a narrow bridge. This bridge is traversed from end to end by a very narrow longitudinal canal, the *central canal* (*c. c*), lined by epithelium, so that the cord is not a solid cylinder, but a tube with an extremely narrow cavity and excessively thick walls.

The section also shows that the cord is not homogeneous, but is composed of two different substances.

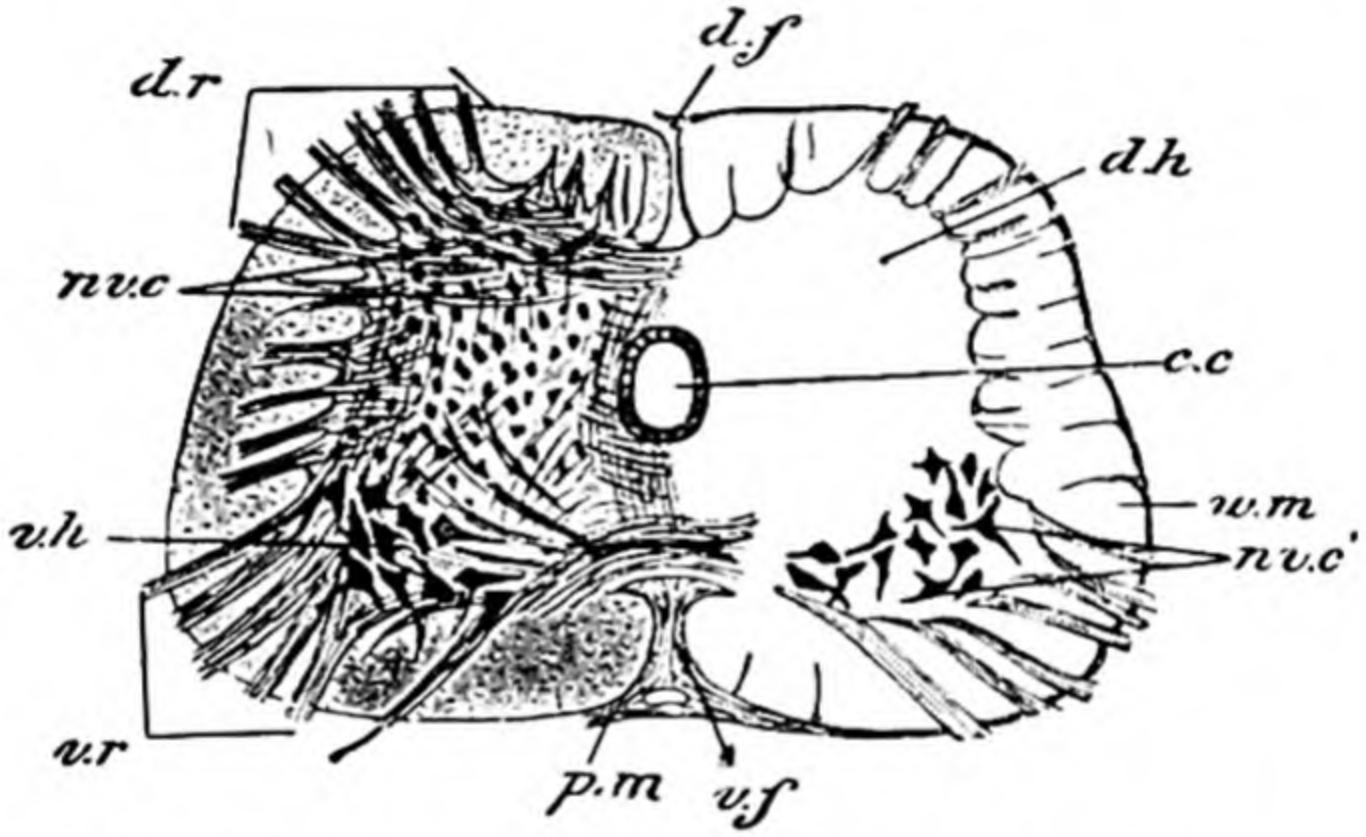


FIG. 50.—Transverse section of spinal cord of Frog. (× 35.)
c.c. central canal; *d. f.* dorsal fissure; *d. h.* dorsal horn of grey matter; *d. r.* fibres of dorsal root of spinal nerve; *nv. c.* nerve-cells of dorsal horn; *nv. c'* nerve-cells of ventral horn; *p. m.* pia mater; *v. f.* ventral fissure; *v. h.* ventral horn of grey matter; *v. r.* fibres of ventral root of spinal nerve; *w. m.* white matter. (After Howes.)

Its outer part is pure white and shining in the fresh cord, and is hence called the *white matter* (*w. m*). Its internal substance has a pinkish colour when fresh, and is called the *grey matter*. The grey matter has a squarish outline in transverse section. It surrounds the central canal, and is continued upwards and downwards, forming what are called the *dorsal* (*d. h*) and *ventral* (*v. h*) *horns* of the grey matter.

The Brain.—Anteriorly the spinal cord passes insensibly into the brain (Fig. 51), which is of somewhat greater diameter than the cord, and is made up of several very distinct parts or divisions. The hindermost division is called the *medulla oblongata* (*Med. obl*); this appears to be simply a widening of the spinal cord (*Sp. cd*), except that on its dorsal surface is a triangular body (D, *ch. plx*^{2}), of a reddish colour in the fresh condition, called the *posterior choroid plexus*; it is simply a thickening of the pia mater containing abundant blood-vessels.

The choroid plexus forms a kind of lid to a triangular cavity (A and D, v^4) excavated in the dorsal region of the medulla oblongata, and called the *fourth ventricle*. The apex of the cavity, which is directed backwards, opens into the central canal of the spinal cord (Fig. 52, v^4, *c. c*), and the fourth ventricle is to be looked upon simply as the anterior part of the central canal which has become widened out and is covered only by a thickened portion of the pia mater.

The fourth ventricle is bounded in front by a narrow ledge of nervous matter (Fig. 51, *Cb*), which would be hardly worthy of being considered as a special division of the brain but for the fact that the corresponding part in many animals—*e.g.*, dogfish, rabbit, man—is a large and important structure. It is called the *cerebellum*.

In front of the cerebellum comes a pair of rounded elevations, the *optic lobes* (Figs. 51 and 52, *Opt. l*). Each contains a cavity, the *optic ventricle* (*Opt. v*), communicating with a narrow median passage, the *iter* (*i*), which is continuous behind with the fourth and in front with the third ventricle. Continued forwards from the medulla oblongata and lying beneath the optic lobes are two bands known as the *crura cerebri* (*Cr. C*).

In front of the optic lobes is an unpaired structure,

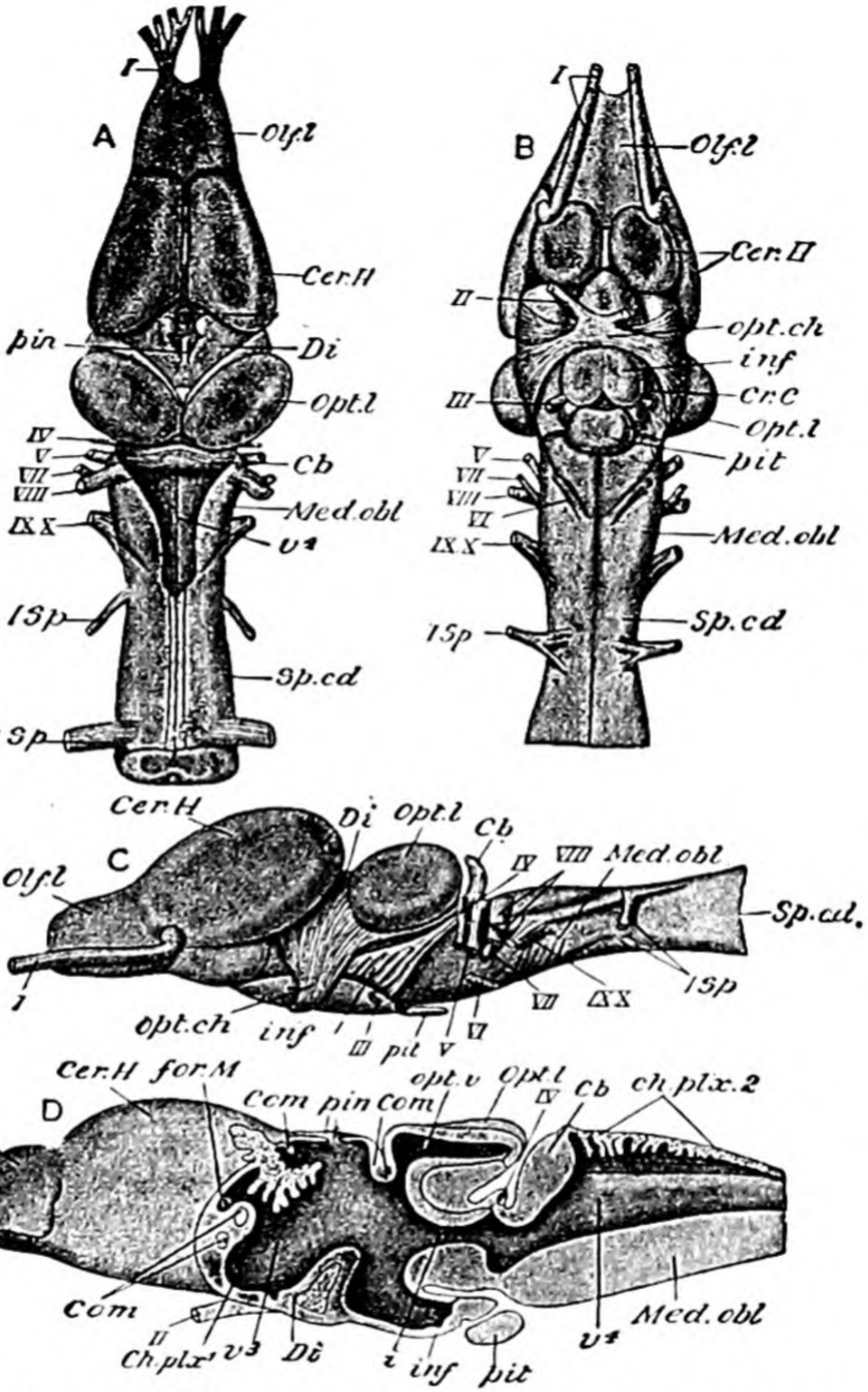


FIG. 51.—Brain of Frog (*Rana temporaria*). A, from above; *B*, from below; C, from the side (× 4); D, in longitudinal vertical section. (× 5.)

Cb. cerebellum; *Cer. H.* cerebral hemispheres; *ch. plx.*[1] anterior and ch. *plx.*[2] posterior choroid plexus (removed in A); *com.* transverse bands of nerve-fibres or commissures connecting the left and right halves of the brain; *Cr. C.* crura cerebri; *Di.* diencephalon; *for. M.* foramen of Monro; *i.* iter, or aqueduct of Sylvius; *inf.* infundibulum; *Med. obl.* medulla oblongata; *Olf. L.* olfactory lobe; *opt. ch.* optic chiasma; *Opt. l.* optic lobe; *opt. v.* optic ventricle; *pin.* stalk of pineal body; *pit.* pituitary body; *Sp. cd.* spinal cord; v^3. third ventricle; v^4. fourth ventricle; I—X, cerebral nerves; *1 Sp.*, *2 Sp.* first and second spinal nerves. (A—C, after Gaupp; D, from Wiedersheim's *Comp. Anatomy*, after Osborn.)

the *diencephalon* or *thalamencephalon* (*Di*). On its upper surface is a small rounded vascular body, the *anterior choroid plexus* (Fig. 51, D, *ch. plx*[1]), formed, like the posterior choroid plexus, of a thickening of pia mater, containing numerous blood-vessels. It helps to roof over a narrow slit-like cavity, the *third ventricle* (v^3), the sides of which are formed by thickenings of nervous matter, the *optic thalami* (*Di*), connected by transverse bands of nerve-fibres (D, *com*). On the ventral surface of the diencephalon, immediately behind the crossing of the optic nerves, is a median swelling, caused by the depression of the floor of the third ventricle to form the *infundibulum* (Fig. 51, *inf*). To this swelling is attached a rounded structure, the *pituitary body* (*pit*). On the dorsal surface, just behind the choroid plexus, is the delicate stalk (*pin*) of the *pineal body*—the vestige of a sensory apparatus between the skull and the skin, which in some lizards, for example, has the structure of a small eye situated on the top of the head, and which was probably functional in the ancestors of the frog. We shall meet with other examples of such *vestigial organs* in the course of our studies.

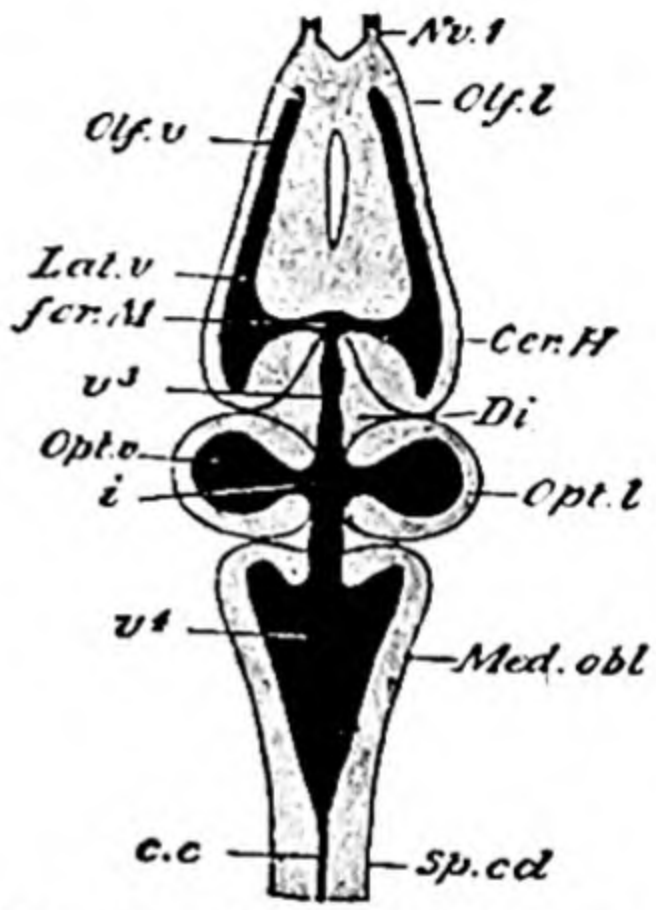


FIG. 52.—Diagrammatic horizontal section of Frog's brain.
c. c. central canal; *Cer. H.* cerebral hemisphere; *Di.* diencephalon; *for. M.* foramen of Monro; *i.* iter; *Lat. v.* lateral ventricle; *Med. obl.* medulla oblongata; *Nv. 1*, olfactory nerve; *Olf. l.* olfactory lobe; *Olf. v.* olfactory ventricle; *Opt. l.* optic lobe; *Opt. v.* optic ventricle; *Sp. cd.* spinal cord; *v. 3*, third ventricle; *v. 4*, fourth ventricle. (After Ecker & Wiedersheim.)

In front of the diencephalon comes a pair of long, oval bodies, wider behind and narrower in front. These are the *cerebral hemispheres* (*Cer. H*). Each contains a cavity, the *lateral ventricle* (*Lat. v*), which communicates with the third ventricle by a small aperture, the *foramen of Monro* (*for. M*).

Lastly, each cerebral hemisphere is continued forwards by a rounded *olfactory lobe* (*Olf. l*), which is fused with its fellow of the opposite side, the single mass lying in the posterior compartment of the girdle-bone (p. 38). The lateral ventricles are continued forwards into the olfactory lobes, forming the small *olfactory ventricles* (Fig. 52, *Olf. v*).

The brain, like the spinal cord, is formed of grey and white matter, but differently arranged. In the olfactory lobes, cerebral hemispheres, and diencephalon the white matter is internal, and the grey forms a thin outer layer or *cortex*. In the optic lobes and medulla the grey matter is mainly around the ventricles, and the white matter more external.

As in the early stages of development the brain is differentiated into three regions from which the parts enumerated above are ultimately derived, the adult brain is also usually said to be divided into three regions, known respectively as fore-brain, mid-brain, and hind-brain. The fore-brain consists of the olfactory lobes, the cerebral hemispheres, and the diencephalon; the mid-brain of the optic lobes and the crura cerebri; and the hind-brain of the medulla and the cerebellum.

Like the spinal cord, the whole brain is covered with pia mater, densely pigmented in the region of the optic lobes, and the cranial cavity in which it is contained is lined with dura mater.

The Spinal Nerves.—The spinal nerves arise symmetrically from the spinal cord on the two sides of the body,

and pass out from the neural canal through the intervertebral foramina (p. 33).

There are altogether nine or ten pairs of spinal nerves in the adult frog (Fig. 53, I—IX), each of which on leaving the neural canal divides into a smaller dorsal and a larger ventral branch (Figs. 54 and 55). The first pair leaves the cord through the intervertebral foramina between the first and second vertebræ. Each passes at first directly outwards, its large ventral branch, known as the *hypoglossal*, turning forwards, and going to the muscles of the tongue (Fig. 55, 1 *Sp.*).

The second pair (Fig. 53, *II*) is very large; it emerges between the second and third vertebræ, and each is soon joined by the small third nerve (*III*), which emerges between the third and fourth vertebræ, as well as by a small branch or two from the first, thus forming a simple network or *plexus*—the *brachial plexus* (*br. pl*), from which pass off nerves to the fore-limb supplying both skin and muscles.

The fourth, fifth, and sixth nerves take a very similar course. The fourth (*IV*) emerges between the fourth and fifth vertebræ, the fifth (*V*) between the fifth and sixth, and the sixth (*VI*) between the sixth and seventh. They all pass obliquely backwards, and supply the walls of the body, being distributed to both skin and muscles.

The seventh, eighth and ninth nerves supply the muscles and skin of the hind-limbs. The seventh (*VII*) leaves the neural canal between the seventh and eighth vertebræ, the eighth (*VIII*) between the eighth and ninth, and the ninth (*IX*) between the ninth vertebra and the urostyle. They all pass almost directly backwards, and are united with one another by oblique cross branches so as to form the *sciatic plexus* (*sci. pl*), from which are given off, amongst others, two nerves

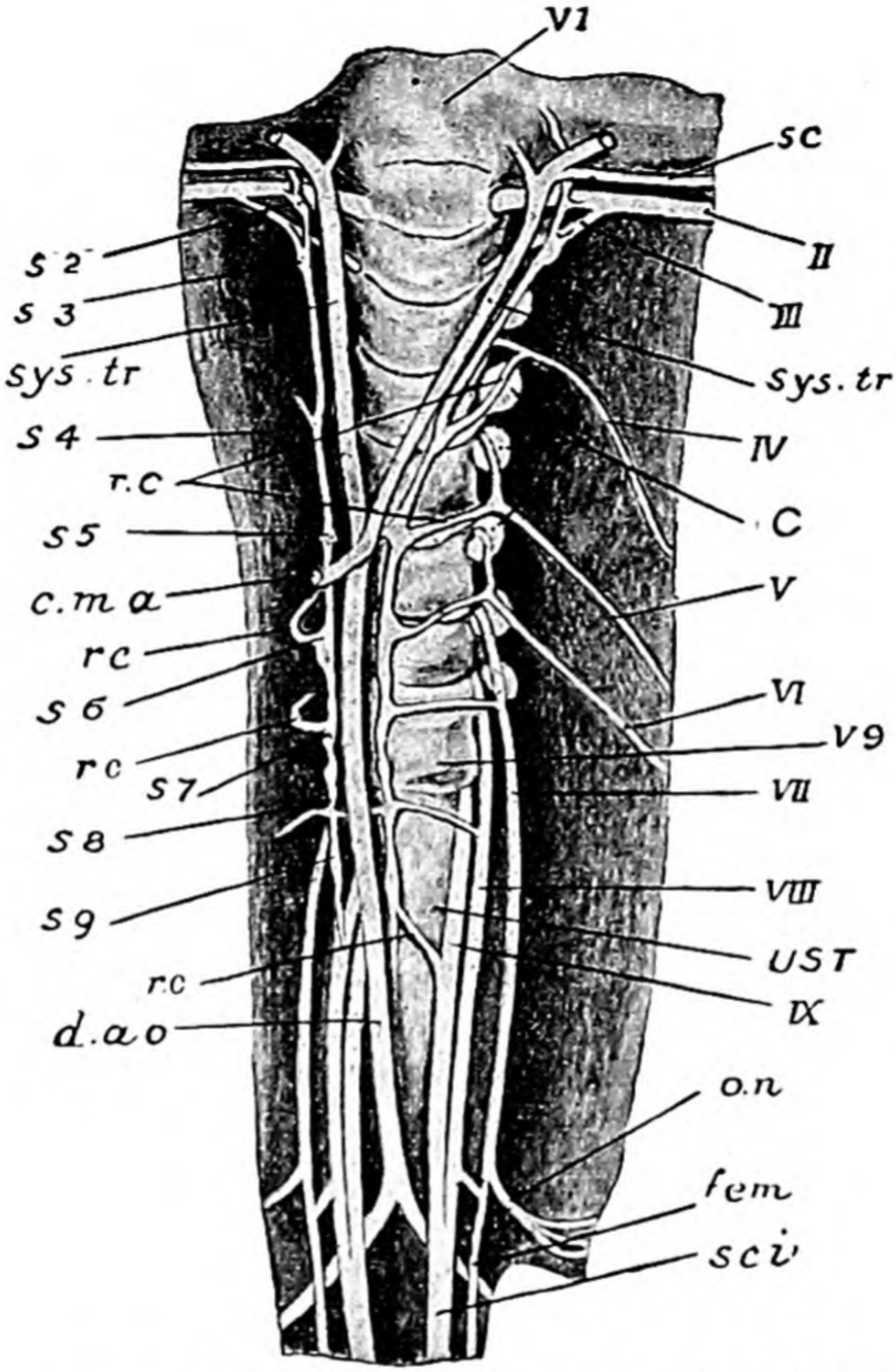


FIG. 53.—The ventral branches of the spinal nerves and the sympathetic of the Frog (*R. trigina*), ventral view. The dorsal aorta has been pulled over a little to the right, and the spinal nerves and the sympathetic are fully shown on the left side only. (B.L.B.)

II—IX, spinal nerves; *C.* calcareous bodies which surround the spinal ganglia; *c. m. a.* cœliaco-mesenteric artery; *d. ao.* dorsal aorta; *fem.* femoral nerve; *il. a.* iliac artery; *o. n.* obturator nerve; *r. c.* rami communicantes or communicating branches between the sympathetic and spinal nerves; *sc.* subclavian artery; *sci.* sciatic nerve; *S2*—*S9*, ganglia on the sympathetic cord; *sys. tr.* systemic trunk; *ust.* arostyle; V^1—V^9, centra of vertebræ.

to the leg, the largest of which, the *sciatic nerve* (*sci*), being that already mentioned in the chapter on the muscular system (p. 59).

The tenth is a very small nerve and in the common Indian frog is very frequently absent altogether, or present on one side only. It emerges when present through a small aperture in the side of the urostyle (p. 34).

It will be noticed that while the large ventral branch of the first spinal nerve—the hypoglossal—supplies muscles only, and is therefore a *motor nerve*, all the others go to both muscles and skin, and are therefore both *motor* and *sensory*, or *mixed nerves*. They all branch out in a complex manner, and are traceable to the remotest parts of the body.

The Sympathetic Nerves.—On either side of the dorsal aorta is a very delicate nerve, having at intervals little swellings called *ganglia*, each of which is connected with a spinal nerve by a communicating branch (Figs. 53 and 55, *s2—s9*, *sy*, *rc*). In front of the point where the dorsal aorta (*D. Ao*) is formed by the union of the two systemic trunks (*Ao*), these two *sympathetic nerves*, as they are called, are continued forward, one on either side of the vertebral column, towards the head, when they enter the skull and become connected with certain of the cerebral nerves.

Each sympathetic nerve has altogether nine or ten ganglia, each connected with one of the spinal nerves, and from the ganglia branches are given off which supply the heart and blood-vessels, the stomach, intestine, liver, kidneys, reproductive organs, and urinary bladder.

Origin of the Spinal Nerves.—The mode of origin of the nerves from the spinal cord is peculiar and characteristic. Traced towards the cord, each nerve is found, on

reaching the intervertebral foramen from which it emerges, to divide into two—a *dorsal root* which springs from the dorsal, and a *ventral root* which arises from the ventral region of the cord (Fig. 54, *d. r*, *v. r*). The dorsal root is distinguished from the ventral by being dilated into a *ganglion* (*gn*). In Fig. 53 these ganglia lie hidden within certain calcareous bodies (*C*) in this region. If the centra of all the vertebræ are removed, it is seen that the spinal cord is a good deal shorter in length than the neural canal which it occupies, and consequently the roots of the seventh, eighth, and

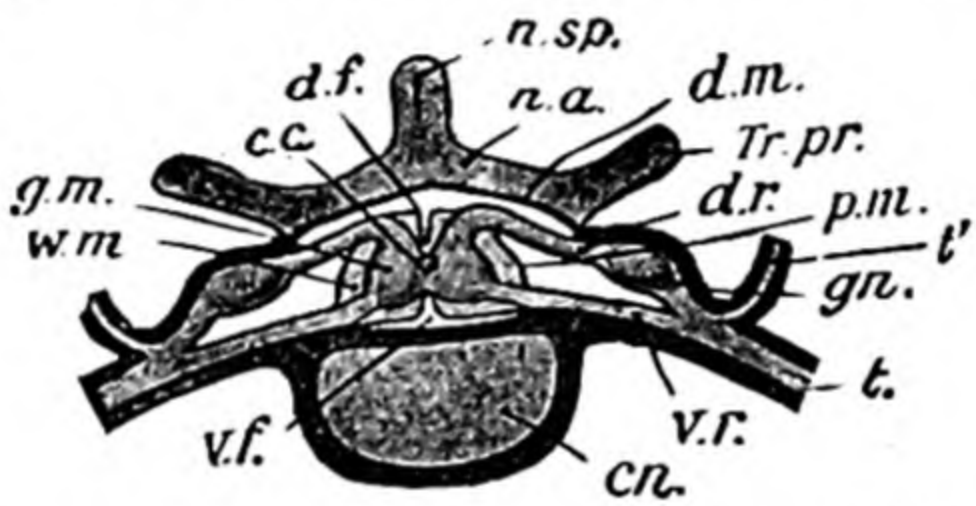


FIG. 54.—Transverse section through the vertebral column and spinal cord of the Frog, to show the mode of origin of the spinal nerves. (× 6.)
c. c. central canal; *cn.* centrum; *d. f.* dorsal fissure; *d. m.* dura mater; *d. r.* dorsal root; *g. m.* grey matter; *gn.* ganglion of dorsal root; *n. a.* neural arch; *n. sp.* neural spine; *p. m.* pia mater; *t.* nerve trunk (ventral branch), *t'.* dorsal branch; *Tr. pr.* transverse process; *v. f.* ventral fissure; *v. r.* ventral root; *w. m.* white matter. (After Howes.)

ninth nerves have to run very obliquely, in order to pass out of their respective intervertebral foramina. The filum terminale, together with roots of these nerves, presents an appearance not unlike a horse's tail, and the name *cauda equina* is consequently given to them.

Cerebral Nerves.—There are ten pairs of cerebral nerves, some of which are purely sensory, some purely motor, some mixed.

The *first* or *olfactory nerve* (Fig. 51, *I*) arises from the olfactory lobe, and passes through a hole in the transverse partition of the girdle-bone. Each is distributed

to the mucous membrane of the nasal sac or organ of smell of the same side, and is purely sensory.

The *second* or *optic* (*II*) is a large nerve which springs from the ventral surface of the diencephalon. At their origin the right and left optic nerves have their fibres intermingled, forming a structure something like a St. Andrew's Cross and called the *optic chiasma* (*opt. ch*), the other limbs of the cross passing upwards and backwards to the optic lobes. The optic nerve makes its exit from the brain-case through the optic foramen, and is distributed to the retina, a delicate membrane which lines the eye-ball, and is, as we shall see, the actual organ of sight. This nerve also is purely sensory.

The *third* or *oculomotor* (*III*) is a small nerve arising from the crus cerebrum beneath the optic lobe close to the median line. It passes through a small hole in the side of the skull behind the optic foramen, and supplies four out of the six muscles by which the eye-ball is moved, and is purely motor.

The *fourth* or *pathetic* (*IV*) is a very small nerve leaving the dorsal surface of the brain between the optic lobes and the cerebellum, and making its exit from the skull above the third nerve. It is also purely motor, supplying one of the muscles of the eye—the superior oblique.

The *fifth* or *trigeminal* (Figs. 51 and 55, *V*) is a large nerve arising from the side of the medulla oblongata. Its root dilates to form a ganglion, the *Gasserian ganglion*, and leaves the skull by the large aperture noticed in the pro-otic bone. It owes its name to the fact that it soon divides into three main branches; one, the *ophthalmic* (Fig. 55, V^1), going to the skin of the snout; another, the *maxillary* (V^2), to the upper lip and lower eyelid; and the third, or *mandibular* (V^3), to the muscles and skin of the lower jaw. The trigeminal is a mixed nerve.

The *sixth* or *abducent* (Fig. 51, *VI*) is a very small motor nerve arising from the ventral aspect of the medulla, close to the median line, and supplying one of the muscles of the eye-ball called the posterior rectus.

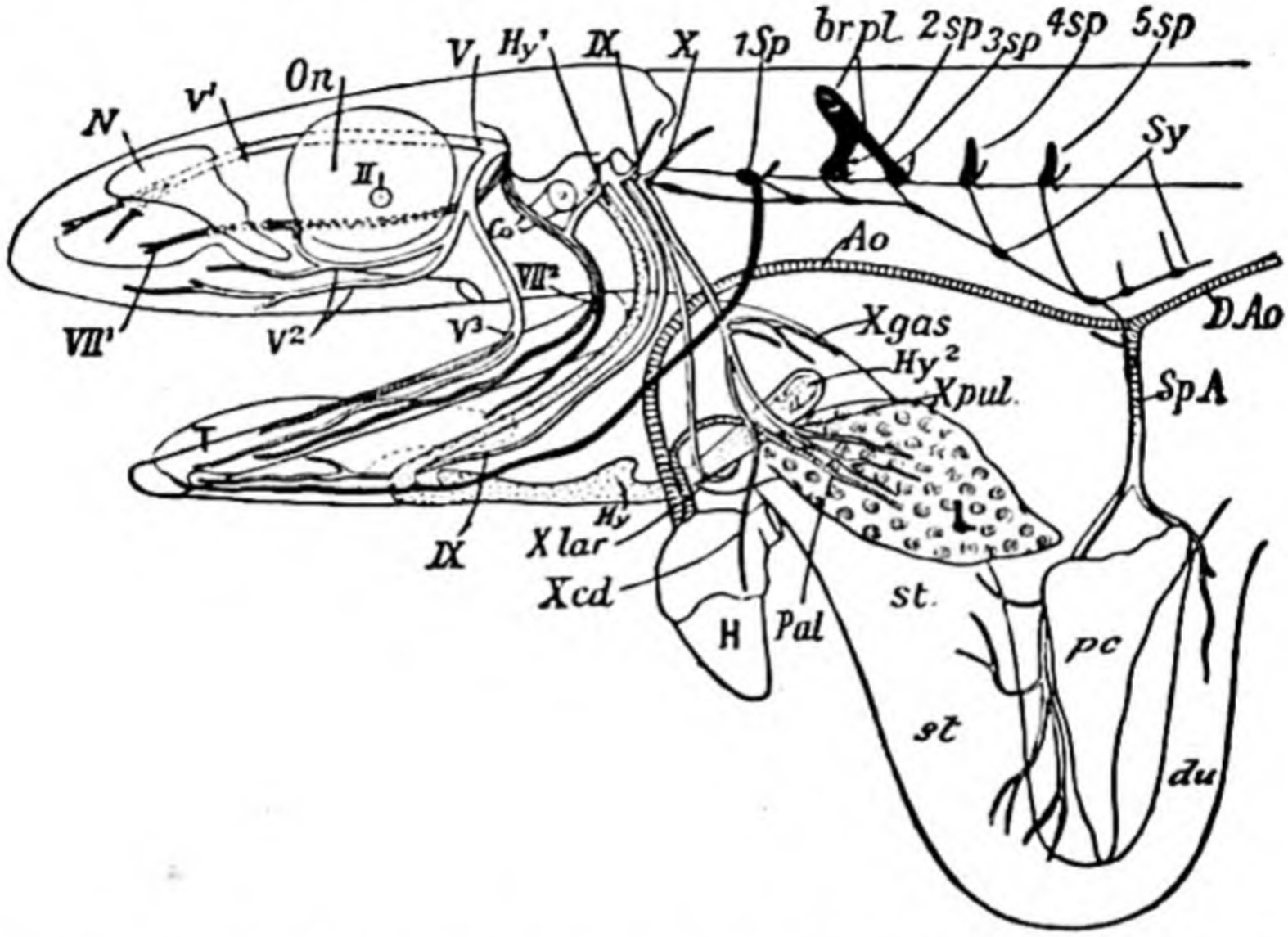


FIG. 55.—Dissection of the head and anterior part of the body of the Frog from the left side, to show the distribution of the fifth, seventh, ninth, and tenth cerebral nerves, as well as of the hypoglossal and part of the sympathetic. (× 1½.)

Ao. systemic arch; *br. pl.* brachial plexus; *co.* columella; *D. ao.* dorsal aorta; *du.* duodenum; *H.* heart; *Hy.* body of hyoid; Hy^1. anterior, and Hy^2. posterior horns of hyoid; *L.* lung; *N.* olfactory sac; *On.* orbit; *pc.* pancreas; *Pul.* pulmonary artery; *Sp. A.* cœliaco-mesenteric artery; *st.* stomach; *Sy.* sympathetic; *II.* cut end of optic nerve; V^1 ophthalmic, V^2. maxillary, and V^3. mandibular branch of trigeminal (*V*); VII^1 palatine, and VII^2 hyomandibular branch of facial; *IX.* glossopharyngeal; *X.* vagus; *Xcd.* cardiac, *Xgas.* gastric, *Xlar.* laryngeal, and *Xpul.* pulmonary branch of vagus; *1 Sp.* first spinal nerve (hypoglossal); *2 sp.*—*5 sp.* second to fifth spinal nerves. (After Howes, slightly modified.)

The *seventh* or *facial* nerve (Figs. 51 and 55, *VII*) arises just behind the fifth and soon joins the Gasserian ganglion. Both it and the sixth leave the skull by the same aperture as the fifth. It divides into two branches, one of which, the *palatine* (Fig. 55, VII^1), supplies the

mucous membrane of the roof of the mouth, and the other, or *hyomandibular* (*VII*²), sends branches to the skin and muscles of the lower jaw and to the muscles of the hyoid. It is a mixed nerve.

The *eighth* or *auditory* nerve (Fig. 51, *VIII*) arises from the medulla just behind the seventh, passes through an aperture in the inner wall of the auditory capsule, and is distributed to the auditory organ or membranous labyrinth (see Figs. 12 and 62). It is the nerve of hearing, and is purely sensory.

The *ninth* or *glossopharyngeal* (Figs. 51 and 55, *IX*) arises behind the auditory nerve. It sends a branch to join the facial, and supplies the mucous membrane of the tongue and pharynx as well as certain small muscles connected with the hyoid. It is also a mixed nerve.

The *tenth* or *vagus* (Figs. 51 and 55, *X*) is a large nerve arising in common with the ninth, and dilating, shortly after leaving the skull, into a *vagus ganglion*. It supplies the larynx (*Xlar*), the heart (*Xcd*), the lungs (*Xpul*), and the stomach (*Xgas*), and is therefore often known as the *pneumogastric*. It has thus an extraordinarily wide distribution (vagus = wandering), being in fact the only cerebral nerve which supplies parts beyond the head. It is a mixed nerve, and contains many motor fibres, but its branches—some of which have to do with the regulation of the heart's contraction and with respiration—are better described as *efferent* and *afferent* than as motor and sensory: the meaning of these terms will be explained later on. The ninth and tenth nerves leave the skull close together through the aperture noticed in the exoccipital bone.

The sympathetic nerve (*Sy*) extends forwards from its junction with the first spinal nerve, joins the vagus, and finally ends anteriorly in the Gasserian ganglion.

Microscopic Structure of Nervous Tissue.—Nervous tissue consists of cells provided with processes for the purpose of receiving and conducting impulses. Every such cell or *neuron* (Fig. 57) consists of (1) a cell-body, containing the nucleus, (2) a long process known as the *neuraxon* (*nx*), along which impressions from the exterior are brought to the cell or impulses are carried away from it, and (3) other processes, usually short, numerous, and branching, known as *dendrons* or *dendrites*, which convey the impression to other neurons or along which the impulses reach the cell. The axon is often of very great length and forms the basis of a *nerve-fibre*. Examination of a piece of nerve under the microscope shows it to be composed, like striped muscle, of cylindrical fibres, bound together by connective-tissue. The latter is much more abundant than in muscle, and in particular forms a thick sheath round the nerve which must be torn off before the *nerve-fibres* are reached.

Each fibre (Figs. 56 and 57) is a cylindrical cord in which three parts can be distinguished. Running along the axis of the fibre is a delicate protoplasmic strand, the *neuraxon* or *axis-fibre* (*nx*). Around this is a sheath formed of a fatty substance and known as the *medullary sheath* (*m. s*);[1] and, finally, investing the whole fibre is a delicate, structureless membrane, the *neurolemma* (*ne*). At intervals the medullary sheath is absent, and a *node* (*n. R.*) is produced, where the fibre consists simply of the neuraxon covered by the neurolemma. Underlying the neurolemma are found at intervals *nuclei* (*ns*), which, however, do not belong to it, but have a small amount of granular cytoplasm of their own.

[1] The medullary sheath may be absent in certain nerve-fibres (*e.g.*, in the sympathetic and olfactory nerves). Such fibres are described as non-medullated nerve-fibres.

In the ganglia are found, not only nerve-fibres, but neurons, which are usually termed *nerve-cells* (Fig. 57): these are of a relatively large size, each with a large nucleus and nucleolus. In the spinal ganglia (B) the cell-body is produced into two processes, which come off from the cell by a common stalk. One of these processes (the *neuraxon*) becomes the axis of a peripheral nerve-fibre; the other (*dendron*) is also a protoplasmic process which passes into the spinal cord and sends off branches, each branch finally ending in a complicated branch-work or arborisation, which is interlaced, but not actually continuous, with a similar arborisation arising from a neuron in the spinal cord or brain (Fig. 58).

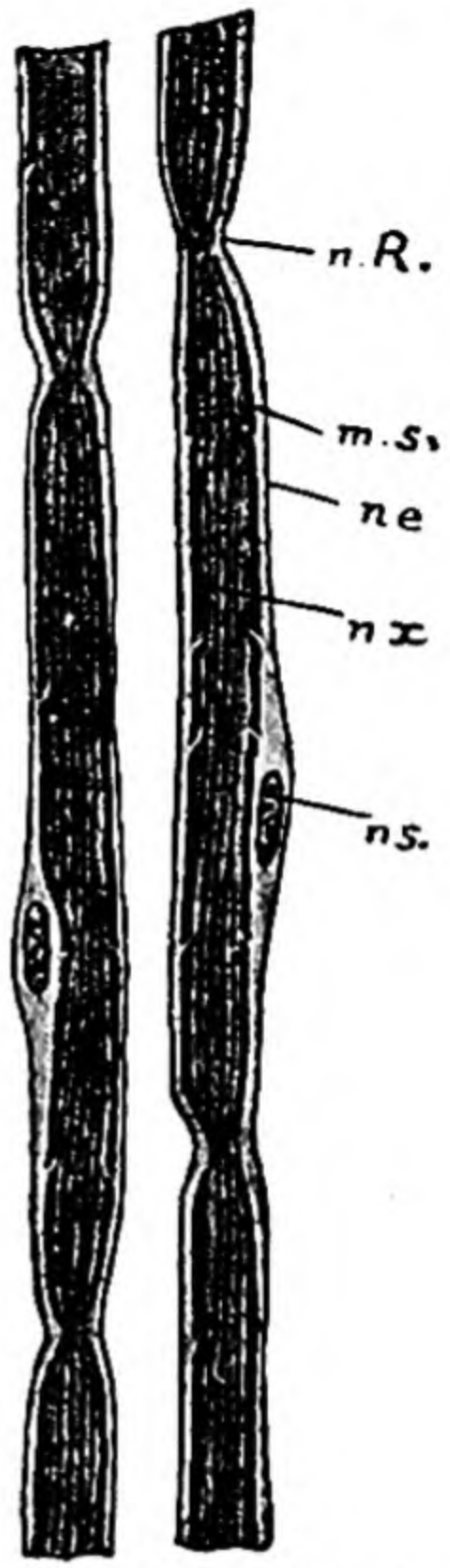


FIG. 56.—Medullated nerve-fibres, stained with osmic acid and highly magnified.
ne. neurolemma; *ns.* nuclei of the sheath; *m. s.* medullary sheath; *nx.* neuraxon; *n. R.* node of Ranvier.

The white matter of the brain and spinal cord consists of nerve-fibres, those in the cord having a longitudinal direction; the grey matter contains numerous "multipolar" nerve-cells, each giving off numerous dendrons and one axon, which is continuous with a neuraxon (Figs. 50 and 57, A); they are enclosed in a tissue formed partly of the axis-fibres of nerves which enter the grey from the white matter, losing their medullary sheath as they do so, and partly of a delicate supporting tissue called *neuroglia*, in which the other elements are imbedded.

Functions of the Spinal Cord: Reflex Action.—In the fourth chapter you learned that a muscle may be

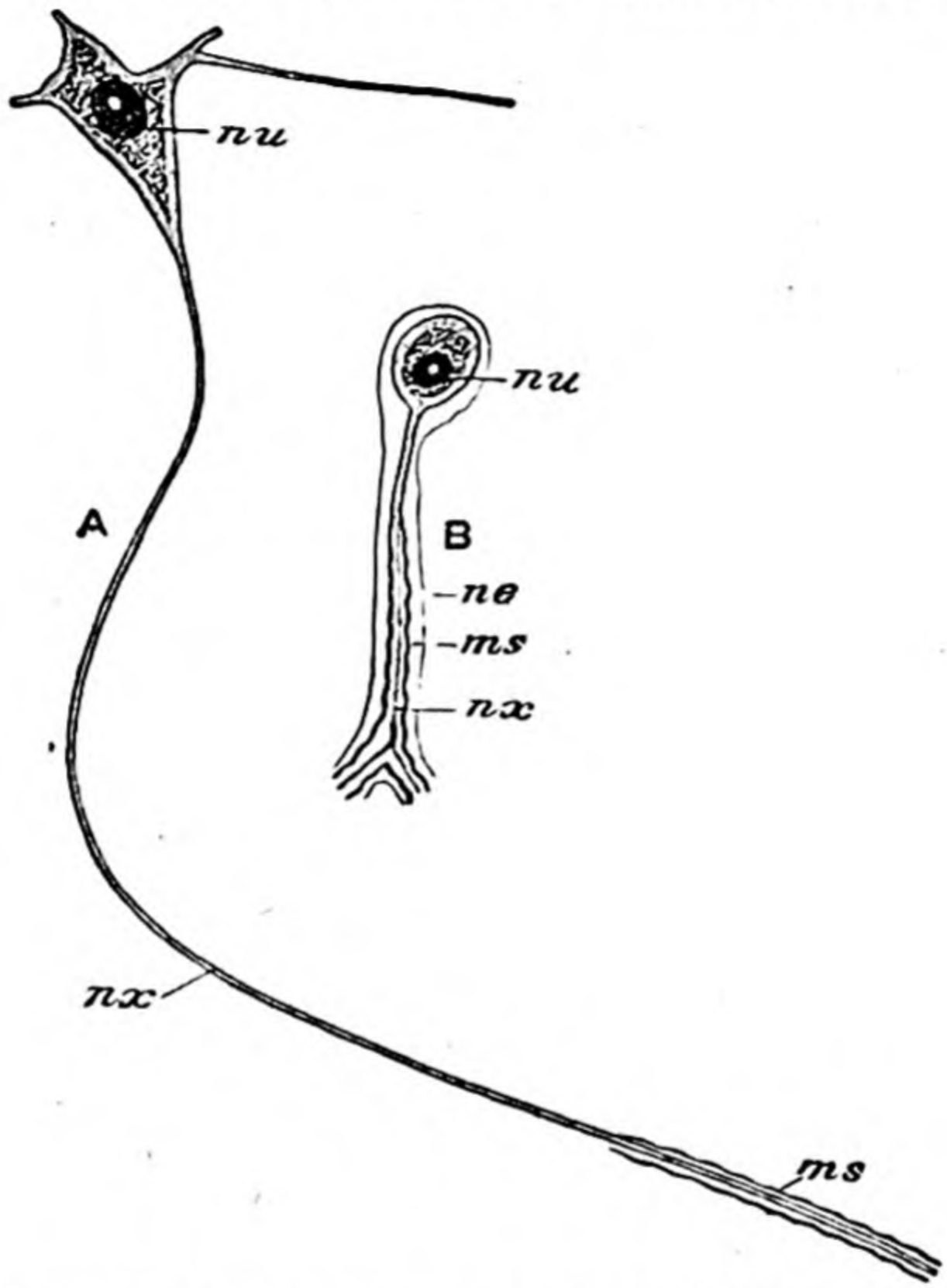


FIG. 57.—A, nerve-cell from the grey matter of the spinal cord of a Frog, and the nerve-fibre arising from it (neurolemma not shown); B, nerve-cell from the ganglion of a dorsal root. (× about 200.)
ne. neurolemma; *nu*. nucleus; *nx*. neuraxon; *ms*. medullary sheath. (After Howes.)

made to contract by a stimulus applied either to the muscle itself or to its nerve. You are now in a position to pursue a little further the subject of the control of various parts of the body by the nervous system.

ing an increased secretion of gastric juice. The secretion of other glands is regulated in a similar way. In some cases, however, it has been proved that the nerves of a gland do not act simply by producing dilatation of the capillaries, but have a direct effect upon the gland-cells, causing an increased secretion.

You will thus note that there are nerve-fibres carrying impulses to the central nervous system which have nothing to do with sensation, and fibres carrying impulses from the central nervous system which have nothing to do with motion, but result in increased secretion or in stoppage of motion. It is therefore best to use the term *afferent* (which includes sensory) for a nerve carrying an impulse to the brain or spinal cord, and *efferent* (including motor) for one carrying an impulse from the brain or spinal cord.

Functions of the Nervous System : Summary.—To sum up, we have seen that the spinal cord is not only concerned with the conduction of impulses to and from the brain, but is also able to originate well-organised movements in response to an external stimulus. The medulla oblongata originates and regulates the nervous impulses which cause respiratory movements. It also regulates the rate and strength of the beat of the heart (through the vagus and the cardiac branch of the sympathetic), and also, by impulses sent through the vaso-motor nerves, the size of the small arteries. It governs the act of swallowing and the secretion of various digestive and other juices in the body. Along with the cerebellum it brings about the co-ordination of muscular movements. It is thus responsible for all the routine affairs of the body. In addition, it acts as a conductor of all impulses from the cerebral hemispheres and other parts of the brain to the spinal cord and from the spinal cord to the cerebral hemispheres. The cerebral hemi-

spheres are the seat of sensations, intelligence, will and emotions. The various cerebral and spinal nerves are concerned with the carrying of afferent (sensory) and efferent (motor) impulses of varied character to or from the brain or the spinal cord. The sympathetic nerves chiefly carry impulses which govern the muscular tissue of the viscera and the muscular coat of the small arteries of the various parts of the body. Thus the stomach may be affected through the sympathetic in severe mental distress, which may thus lead to disturbances of digestion; some emotions, such as shame, may lead to blushing, caused by the dilatation of the small blood-vessels of the skin of the face, and others, such as fright, to pallor, caused by constriction of the same vessels. It must be remembered, however, that the sympathetic nerves receive the impulses which they carry, from the central nervous system, and that these impulses do not arise in the sympathetic cord itself.

CHAPTER XI

THE FROG (*continued*): THE ORGANS OF SPECIAL SENSE

In the previous chapter you have learnt how the nervous system controls the various functions of the body, and how voluntary action is absolutely dependent upon the connection of the brain, through the spinal cord, with the nerves. Obviously, in order that the power of voluntary action should be of full use to its possessor, some means of communication with the external world is not only desirable but necessary; the frog, in order to adjust its actions to the circumstances in which it from time to time finds itself, must be able to distinguish friends from enemies, suitable from unsuitable food, darkness from light, heat from cold.

The avenues of communication between the animal and its surroundings are, as in ourselves, the *senses of touch, taste, smell, sight,* and *hearing.*

Touch. The sense of **touch**, including that of *temperature*, is lodged in the whole extent of the skin, which, as you have already learnt, is abundantly supplied with sensory nerves. Many of the nerves terminate in connection with what are known as *tactile cells*—large flattened cells arranged in groups just below the epidermis and around which the ultimate fibres of the sensory nerves are distributed. Stimuli applied to the skin, either by direct touch or by the heat of the sun, are transmitted to the

tactile cells and thence through the sensory nerves to the brain. Notice that the stimulus is transmitted to the nerve-ends through the epithelial cells of the skin; if the skin be wounded and a stimulus applied directly to the tactile cells or the nerves, the sensation is one, not of touch, but of pain.

Taste. The sense of **taste** is lodged in the mucous membrane of the mouth, especially on the tongue and in the neighbourhood of the vomerine teeth, but extending also as far back as the gullet. Certain of the epithelial cells have an elongated form and are arranged in groups known as *taste-buds*, to which the fibres of the ninth and palatine branch of the seventh cerebral nerves, or nerves of taste, are distributed; on the tongue these taste-buds are situated on *papillæ* of the mucous membrane. In this case the stimulus is supplied, not by direct touch or by alteration of temperature, but by the contact of sapid or tasty substances. As before, the stimulus is applied to epithelial cells, and by them transmitted to the nerves and so to the brain, when the sensation of taste becomes manifest. Thus, just as common sensation may be abolished, in any part of the body, in three ways —by destruction of the skin, by cutting the sensory nerve, or by destroying the cerebral hemispheres—so the sense of taste is lost if either the mucous membrane of the mouth is injured or if the glossopharyngeal and palatine nerves are cut, or, again, if the cerebral hemispheres are destroyed.

Smell. The sense of **smell** is lodged in the *nasal* or *olfactory sacs*, which are enclosed in the olfactory capsules of the skull and separated from one another by a partition, the *nasal septum*. Each sac has two apertures, the *external nostril*, opening on the surface of the snout, and the *internal nostril*, opening into the mouth (p. 15). The sacs are lined by a delicate mucous membrane, some of

the epithelial cells of which are of the ordinary columnar type, while others are extremely slender and produced into delicate processes at their free ends. With these latter the fibres of the olfactory nerves are connected, and they are distinguished as *olfactory cells* (Fig. 59). As the epithelial cells of the skin are affected by direct contact or by heat, so the olfactory cells are affected by the minute particles given off from odorous bodies: the contact of these particles acts as a stimulus, which, being transmitted by the olfactory nerves to the brain, gives rise to the sense of smell. This sense can be destroyed—as in the case of feeling and taste—either by destruction of the olfactory mucous membrane or by cutting the olfactory nerves, or by destroying the brain.

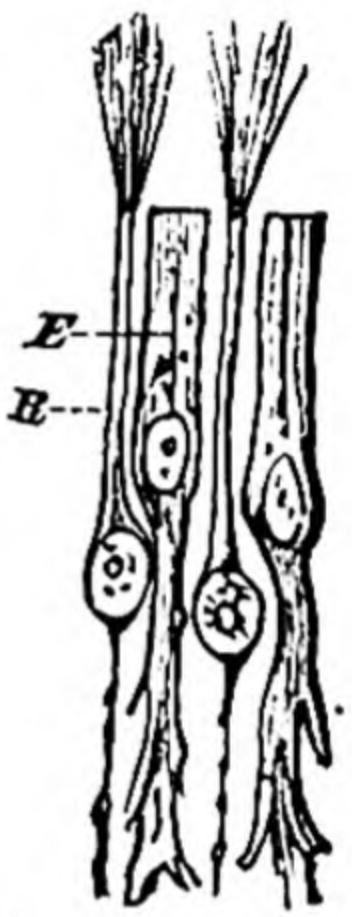


FIG. 59.—Epithelial cells of the olfactory mucous membrane of an Amphibian, highly magnified.
E. interstitial cells; *R*. olfactory cells. (From Wiedersheim's *Comp. Anatomy*.)

Sight. The organ of **sight** or *eye* of the frog is similar in structure to that of man, and it will only be necessary to give a brief outline here.

Each eye (Fig. 60) is a nearly globular organ, and when removed from the orbit and cleaned by dissecting away the attached muscles, etc., two regions can be distinguished in it—an opaque portion of a dark bluish colour which forms some two-thirds of the entire globe and is hidden within the orbit in the entire animal; and a clear, transparent portion which is directed outwards and freely exposed between the eyelids in the living frog. The outer coat of the concealed portion of the eyeball is the *sclerotic* (*scl*) and is formed of cartilage in the frog; the dark colour is due to the presence of a layer of black

pigment which forms one of the internal coats; this will be referred to hereafter. Entering the sclerotic on its inner side, *i.e.*, the side next the brain-case, will be seen the cut end of the optic nerve. The transparent, exposed portion of the eyeball is the *cornea* (*c*), a superficial thin layer of which, or *con-*

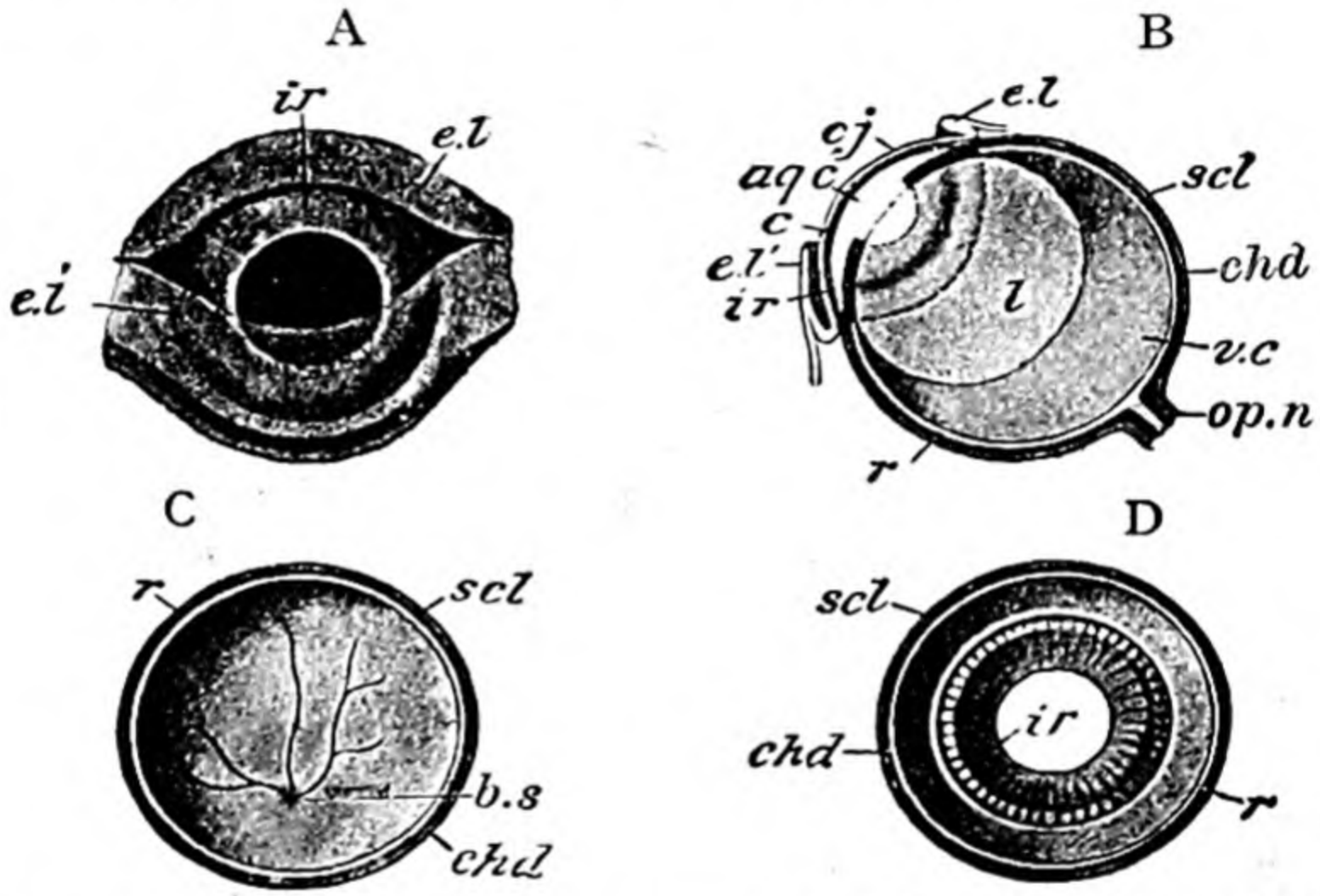


FIG. 60.—The eye of the Frog. A, as seen in the living animal. B, in median longitudinal section, through the plane of the optic nerve. C and D, the two halves of the eye, bisected equatorially; the inner half (C) showing the blind spot. (× 3½.)

aq. c. aqueous chamber; *b. s.* blind spot; *c.* cornea; *chd.* choroid; *cj.* conjunctiva; *e. l.* upper eyelid; *e. l'.* lower eyelid; *ir.* iris; *l.* crystalline lens; *op. n.* optic nerve; *r.* retina; *scl.* sclerotic. *v. c.* vitreous chamber. (After Howes.)

junctiva (*cj*), is continuous with the lining of the eyelids and thus with the skin covering the head; through it can be seen the circular coloured part of the eye, or *iris* (*ir*), with a black spot—really a hole—in its centre, the *pupil*.

The interior of the globe (*v.c*) is filled with a colourless, transparent jelly, the *vitreous humour*, surrounding

which, everywhere except on its anterior side, is a thin semi-transparent membrane, reddish when perfectly fresh, but becoming grey soon after death; this is the *retina* (*r*). Between the retina and the sclerotic is a vascular membrane called the *choroid* (*chd*), the inner face of which, *i.e.*, that in contact with the retina, is coloured black. It is this layer of black pigment which gives the dark tint to the semi-transparent sclerotic in the entire eye; strictly speaking, it belongs to the retina but actually it adheres to the choroid and appears like the innermost layer of that coat. The retina is readily detachable from the choroid, but at the place where the optic nerve enters (*blind spot*, *b. s*) it becomes continuous with the fibres of the latter, which pass through the sclerotic and choroid. The choroid is made up of connective-tissue and contains numerous vessels as well as pigment-cells.

Lying just internal to the pupil is a nearly globular body, perfectly transparent when fresh, the *crystalline lens* (*l*); it is kept in place by a delicate membrane, the *capsule* of the lens. The iris, which covers the anterior face of the lens except where it is perforated by the pupil, is covered on its inner surface with black pigment, and is continuous all round its outer margin with the choroid. Between the iris and the cornea is a space, the *aqueous chamber* of the eye (*aq. c*), which contains a watery fluid, the *aqueous humour*. The main cavity of the eyeball, containing the *vitreous humour*, is called the *vitreous chamber* (*v. c*).

The actual relations of these parts in the entire eye are best grasped in a vertical section, such as is represented in Fig. 60, B. The main part of the eyeball forms a chamber, enclosed by the sclerotic, darkened internally by the choroid and lined by the retina. Into the outer side of this dark chamber is placed a transparent window,

the cornea; behind which, and separated from it by a space containing the aqueous humour, is a vertical curtain, the iris, perforated by an aperture, the pupil. Behind the iris and in close contact with it is the lens, and filling the whole of the dark chamber between the lens and iris and the retina is the vitreous humour.

The whole eye thus has the structure of a camera obscura. The cornea, aqueous humour, lens, and vitreous hunour are a series of transparent media, so arranged that the rays of light from an external object are refracted and brought to a focus on the retina, where they form a greatly diminished and inverted image of the object. The iris is provided with muscles, by means of which the pupil can be enlarged or diminished; it therefore acts as a diaphragm and regulates the amount of light entering the eye. Attached to the capsule of the lens are delicate muscles, by means of which the lens can be shifted to some extent towards the cornea; in this way the focus of the entire apparatus can be altered according to whether the object viewed is nearer or farther from the eye. This arrangement for accommodation is, however, much less highly developed in the frog than in man and the higher animals, in which the relatively smaller lens is flatter and distinctly biconvex in form and is allowed to become more convex anteriorly, through the contraction of the ciliary muscle. Thus the various parts of this complicated organ are so adjusted as to bring the images of external objects at varying distances to an accurate focus on the back part of the interior of the eyeball, *i.e.*, on the retina.

A vertical section of the retina seen under a microscope, reveals a very complex structure (Fig. 61). On its inner face, *i.e.*, the surface in contact with the vitreous humour, is a layer of nerve-fibres (*n. f*), formed

by the ramifications of the optic nerve, which, passing through the sclerotic and choroid, perforates the retina, and spreads out over its inner surface. Next comes a layer of nerve-cells (*g*), and then several layers of fibres and nuclei (*gr*, *nc*); and finally, forming the outer surface of the retina proper, is a layer of delicate, transparent bodies called, from their form, the *rods* (*r*) and *cones* (*c*); these are known from their development to be modified epithelial cells. All these structures are supported by a complex framework of connective-tissue. In close contact with the outer or free ends of the rods and cones is a layer of cells the protoplasm of which is filled with a dense black pigment. It is this *pigment-layer* (*p. ep*) which, as already mentioned, is often counted as part of the choroid.

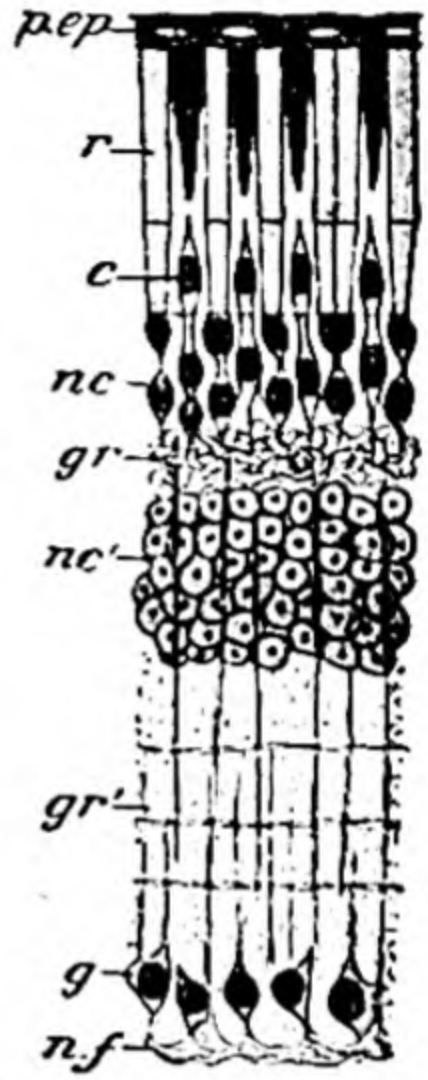


FIG. 61.—Vertical section of Frog's retina. (× 300.)
c. cones; *g.* layer of nerve-cells; *gr*. *gr'*., outer and inner granular layers; *nc*, *nc'*, outer and inner nuclear layers; *n. f.* layer of nerve-fibres; *p. ep.* pigment-epithelium; *r.* rods. (After Howes.)

In spite of its complex structure, the retina is not much more than $\frac{1}{4}$ mm. ($\frac{1}{100}$ inch) thick, and is perfectly transparent. Hence, when an image is formed on it, the rays of light easily penetrate its whole thickness until they are stopped by the opaque layer of pigment. The rays can thus stimulate the rods and cones, and the stimulus is transmitted through the layers of nuclei and nerve-cells to the fibres of the optic nerve, along which it is conveyed to the brain. Thus the actual organ of sight is not the eye as a whole, but the retina: all the rest is to be looked upon as an accessory apparatus,

for focussing and for regulating the admission of light.

As with the other sense-organs, sight may be destroyed by injury to the retina or actual organ of sight, by cutting the optic nerve, or by destroying the brain. But unlike the other sense-organs already considered, that of sight has a complex accessory or focussing apparatus in connection with it, and vision may also be rendered impossible by injury to the cornea or lens.

It is an obvious advantage that the eye of the frog should be capable of movement in any direction, so as to allow the light from any object to enter the pupil. As a matter of fact, the animal can direct its gaze through a very wide range by means of eight muscles connected with the eyeball in the orbit. One of these, the *levator bulbi*, raises the whole eye, causing it to project further on the surface of the head. Another, the *retractor bulbi*, withdraws it, causing it to bulge into the mouth. Four others, the superior, inferior, anterior, and posterior *recti*, rotate it respectively upwards, downwards, forwards, and backwards. And, finally, two *oblique* muscles, the superior and inferior, produce a rotation along an axis joining the optic nerve with the middle of the cornea.

The conjunctiva, which covers the outer surface of the eye and lines the eyelids, is kept moist by the secretion of a lacrymal gland, known as the *Harderian gland*, situated between the eyeball and the orbit in the antero-ventral region. The excess of this secretion is carried away into the olfactory chamber by means of a tube, the *naso-lacrymal duct*.

Hearing.—Each organ of **hearing** (which also serves for *equilibration*), like the organ of sight, consists of an essential portion and an accessory apparatus. The essential organ of hearing is a structure called the *membranous*

labyrinth, contained within the auditory capsule of the skull (Fig. 12), and consisting of a kind of bag of very peculiar and complicated form (Fig. 62). It is made up, in the first place, of two somewhat ovoid sacs separated by a constriction: the dorsal one is called the *utriculus* (*ut*), the ventral the *sacculus* (*s*), and from the latter a small process,

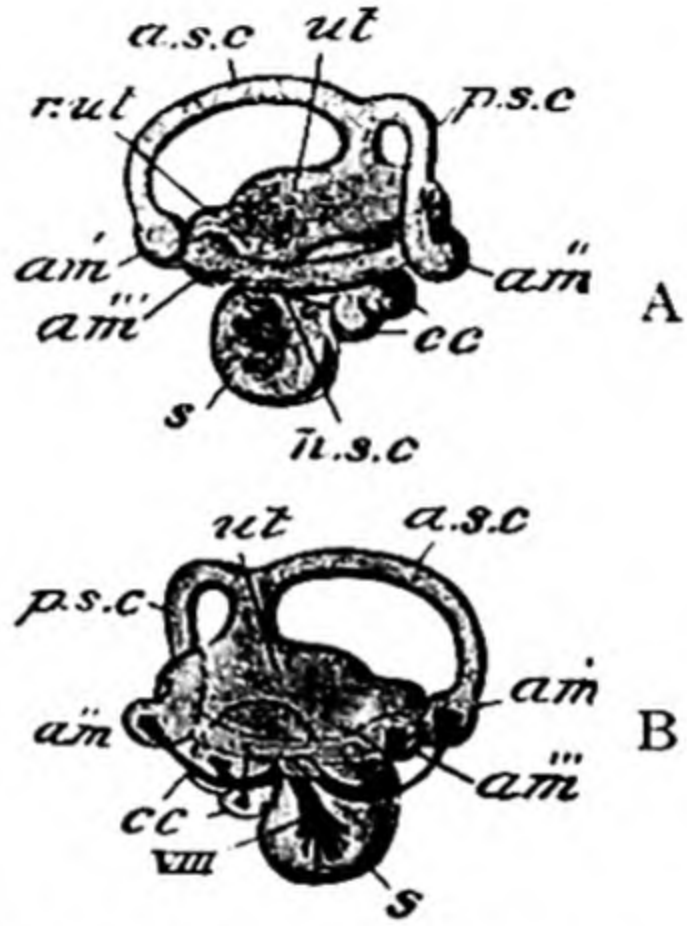


FIG. 62.—The membranous labyrinth of the Frog's ear. A, outer, and B, inner view. (× 6.)
am', *am''*, *am'''*, ampullæ of the semicircular canals; *a. s. c.* anterior semicircular canal; *cc.* cochlea; *h. s. c.* horizontal (external) semicircular canal; *p. sc.* posterior semicircular canal; *r. ut.* recess of the utriculus; *s.* sacculus; *ut.* utriculus; *VIII.* branches of auditory nerve. (After Howes.)

the *cochlea* (*cc*), projects backwards. With the utriculus are connected three tubes, called, from their form, the *semicircular canals*, each of which opens into the utriculus at either end. One of them, the anterior canal (*a.s.c*), is directed forwards; another, the posterior canal (*p.s.c*), backwards; both these are vertical in position and are united to one another at their adjacent ends. The third, the external canal (*h.s.c*),

is directed outwards and has a horizontal position. Each canal has one end dilated into a bulb-like swelling or *ampulla* (*am*); those of the anterior and external canals are at their anterior ends, while that of the posterior canal is at its posterior end.

The whole of this apparatus is filled with a fluid, the *endolymph*, in which are contained calcareous particles, the *otoliths* or ear-stones. It is made of connective-

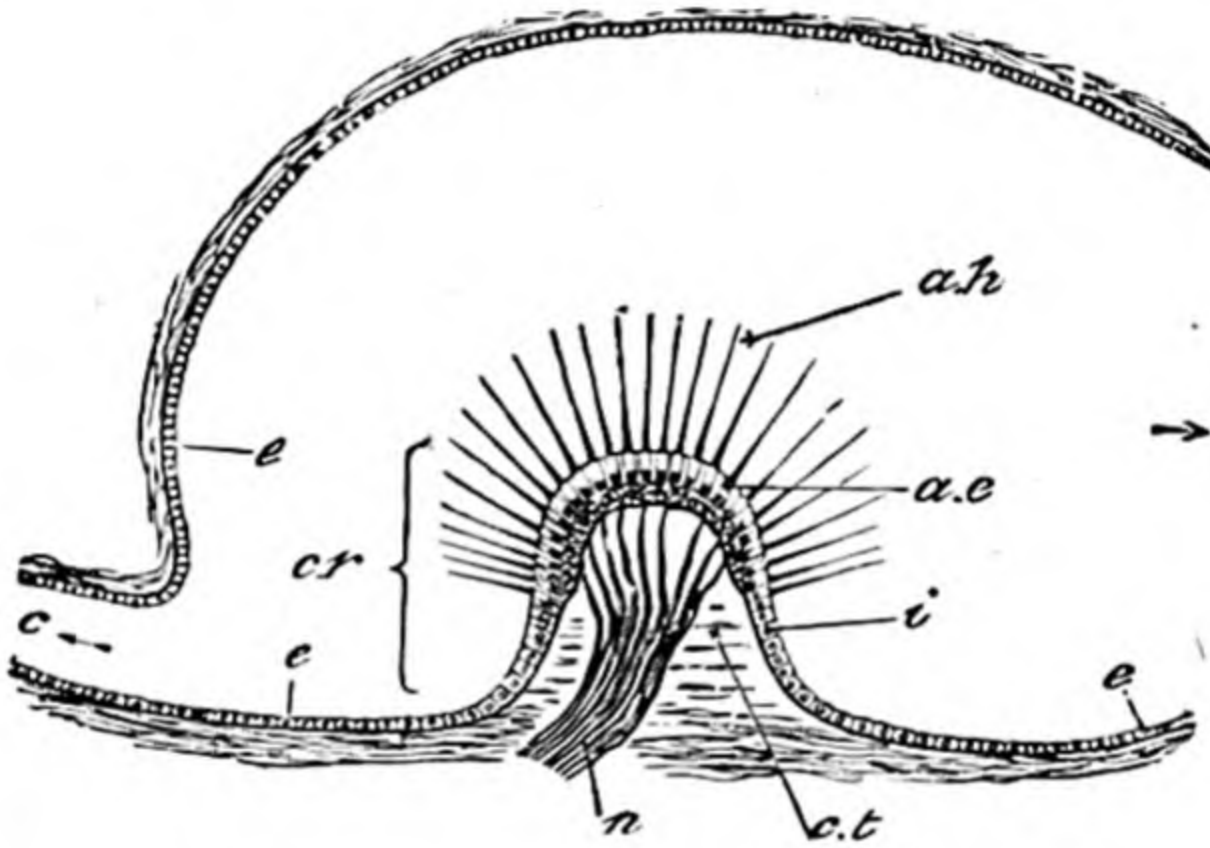


FIG. 63.—Longitudinal section through an ampulla.
a. e. auditory epithelium; *a. h.* auditory hairs; *c.* part of semicircular canal; *c. r.* acoustic spot and ridge; *c. t.* connective-tissue; *e.* epithelium; *n.* nerve; *u.* junction with utriculus. (From Foster and Shore's *Physiology*.)

tissue and lined with epithelium, the cells of which are cubical for the most part; but in certain places the wall is thickened, forming what are called *acoustic spots*, of which there is one to each ampulla, situated on a ridge (Fig. 63), while others occur in the utriculus and sacculus. On these acoustic spots the epithelial cells are greatly elongated, and produced at the surface into delicate processes called auditory hairs: to these cells the fibres of the auditory nerve are distributed.

The membranous labyrinth does not fit tightly into

the cavity of the auditory capsule in which it is contained, a space being left between it and the surrounding bone and cartilage (Fig. 12). This space is filled by loose connective-tissue and a fluid called *perilymph*, by which the membranous labyrinth is surrounded and protected from shocks. As you learnt in studying the skull, the outer wall of the auditory capsule is perforated by a small aperture, the *fenestra ovalis* (Fig. 12, *fen. ov*), in which is fixed the *stapedial plate* (*stp*), a small nodule of cartilage connected with a bony rod or *columella* (*col*), the cartilaginous hammer-shaped outer end of which is fixed to the inner side of the *tympanic membrane* (*tymp. memb*). The columella lies in the *tympanic cavity* (*tymp. cav*), which is bounded externally by the tympanic membrane, internally by the auditory capsule, and at the sides chiefly by muscles and connective-tissue; while below it communicates with the mouth-cavity by the *Eustachian tube* (*eus. t*).

When sound-waves impinge on the tympanic membrane, the vibrations to which they give rise are transmitted by the columella to the stapedial plate, and so to the perilymph. Thence they are communicated to the endolymph and act as stimuli to the auditory cells of the acoustic spots, and the impulses, being carried to the brain by the auditory nerve, give rise to the sensation of sound. Whether or not all the acoustic spots are truly auditory in function is not known: it seems that the semicircular canals are really concerned with the sense of direction and velocity and with the maintenance of equilibrium.

The sense of sound can be destroyed by injury to the membranous labyrinth, by cutting the auditory nerve, by destroying the brain, or—to a great extent at least—by injury to the tympanic membrane or columella.

Notice that the general plan of all the sensory organs,

those of touch, taste, smell, sight, and hearing, is the same. They consist of certain peculiarly modified epithelial cells, specially sensitive to impulses of particular kinds, and in communication, by means of an afferent nerve, with nerve-cells of the brain. The three things—sensory cell, afferent nerve, and brain—form a chain every link of which is necessary for the performance of the sensory function, so that the particular sense in question may be destroyed, not only by destruction of the sense-organ, but also by section of the afferent nerve or by destruction of the brain.

General Physiology—Summary.—Before going on to the next chapter it will be as well to take a final glance at the physiological processes of the frog as a whole (compare Fig. 27). The alimentary canal is the factory in which the raw material of the food is worked up into a form in which it can be used by the various parts of the body. The circulatory organs are the communicating system by which the prepared food is taken to all parts; and they also form a drainage system by which waste matters are collected from all parts and finally ejected by the three main sewers, the skin, lungs, and kidneys. The skin and lungs, besides getting rid of waste matters, serve for the supply of oxygen—a necessary form of gaseous food. The central nervous system forms a sort of headquarters' staff by which the entire body is controlled, the means of communication being the nerves, and the muscles the executive by which the orders from headquarters are executed. And finally the sense-organs may be looked upon as the various branches of an intelligence department by which the headquarters are informed of what is going on outside.

CHAPTER XII

THE FROG (*continued*): REPRODUCTION AND DEVELOPMENT

So far we have considered those parts and organs of the frog which have to do with its welfare as an individual. We have now to consider the organs which are connected with the welfare of the frog as a race, that is, with the propagation of its kind.

The position of the reproductive organs has already been seen (pp. 21 and 23): they must now be examined in more detail. The essential part of these organs in each sex is a pair of bodies known as *gonads*, called in the male *spermaries* or *testes*, and in the female *ovaries*.

Reproductive Organs of the Male.—The spermaries (Fig. 25, *r. spy*, and Fig. 8, *ts*) are a pair of yellow ovoid bodies, each attached by a fold of the peritoneum to the corresponding kidney, and having connected with it a fat-body (*cp. ad*). From the inner margin of each spermary spring a number of delicate tubes, the *efferent ducts* (Fig. 25, *ve*), which run in the fold of the peritoneum to the kidney. Entering this organ near its inner edge, they communicate with the kidney tubules along which the spermatic fluid passes into the ureter. The spermatic fluid (p. 10), is thus carried off by the same duct as the urine; the ureter is therefore often called, in the male the *urinogenital duct*. In the male *R. tigrina* the portion of the duct lying behind the kidney is dilated, and narrows again before joining the cloaca.

The spermary itself contains a narrow, irregular, central cavity, from which the efferent ducts proceed and into which open a number of short tubes or *crypts* (Fig. 64, A). These are lined with a *germinal epithelium* (*t. e*), the cells of which divide and subdivide, forming groups of smaller cells. Each of the latter undergoes a remarkable change, becoming converted into a rod-like body, produced into a long thread, which performs lash-

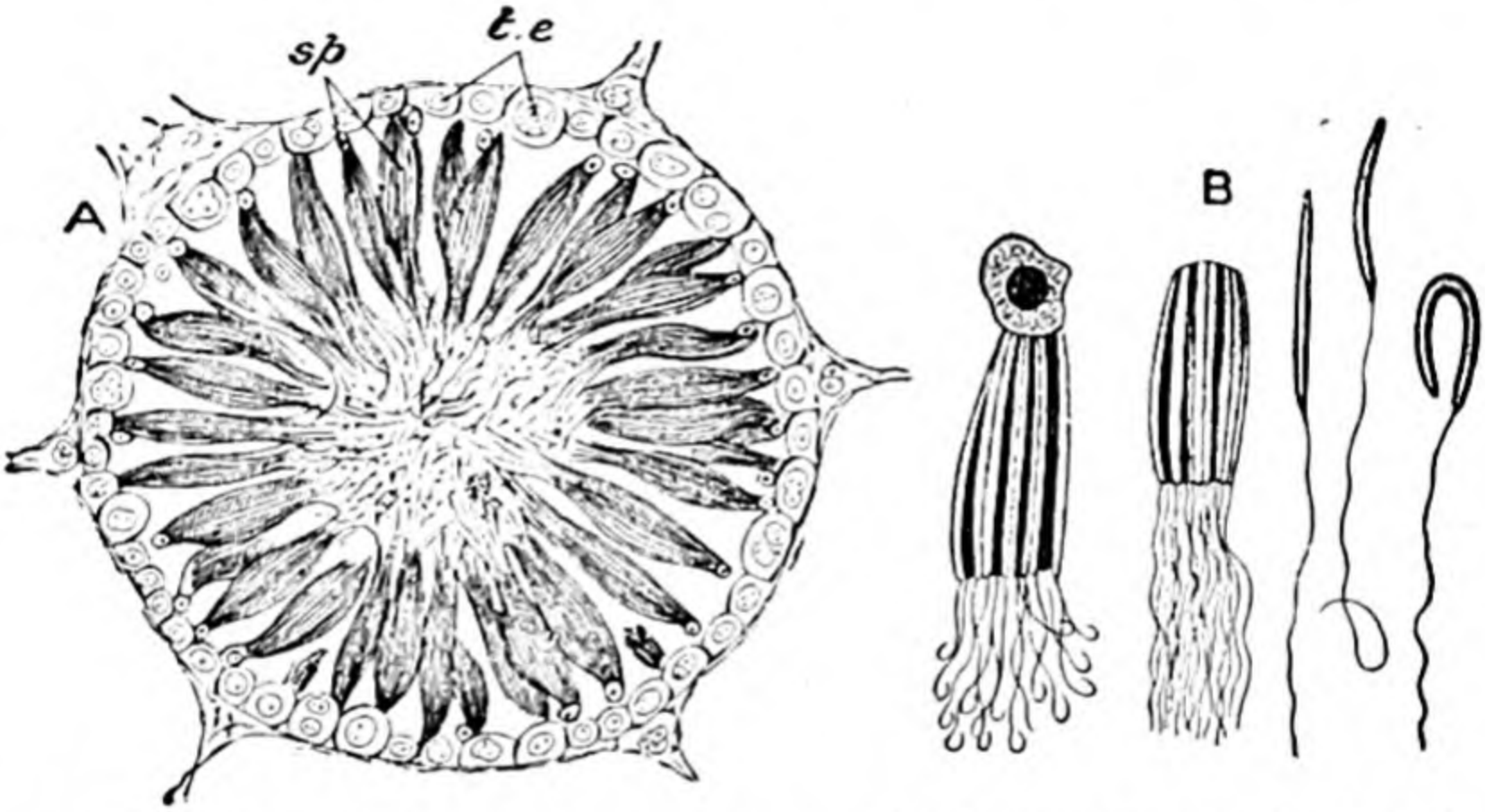


FIG. 64.—A, transverse section of a crypt of the Frog's spermary. (× about 350.)
B, stages in the development of the sperms. (× 500.)
sp. bundles of sperms; *t.e*. germinal epithelium. (A, after Blomfield; B, after Howes.)

ing movements, very much like those of the cilia in ciliated epithelium. These bodies are called *sperms* or *spermatozoa* (Fig. 64, A, *sp*, and B); in spite of their peculiar form, they are cells, the rod-like portion, or *head*, being the nucleus, and the delicate vibratile part, or *tail*, the protoplasm. In the breeding season the cavities of the testes are full of sperms floating in a fluid. Thus the spermatic fluid, like the blood, owes its distinctive character to the cells floating in it.

Reproductive Organs of the Female.—Each *ovary* (Fig. 5, *l. ovy*) is a greatly folded sac with thin walls and a large cavity divided up by partitions. It is attached to the dorsal body-wall by a fold of peritoneum. As we have seen (p. 23), its surface is studded all over with little rounded projections, each of which is an *ovarian follicle*, and contains an egg. The egg or *ovum*

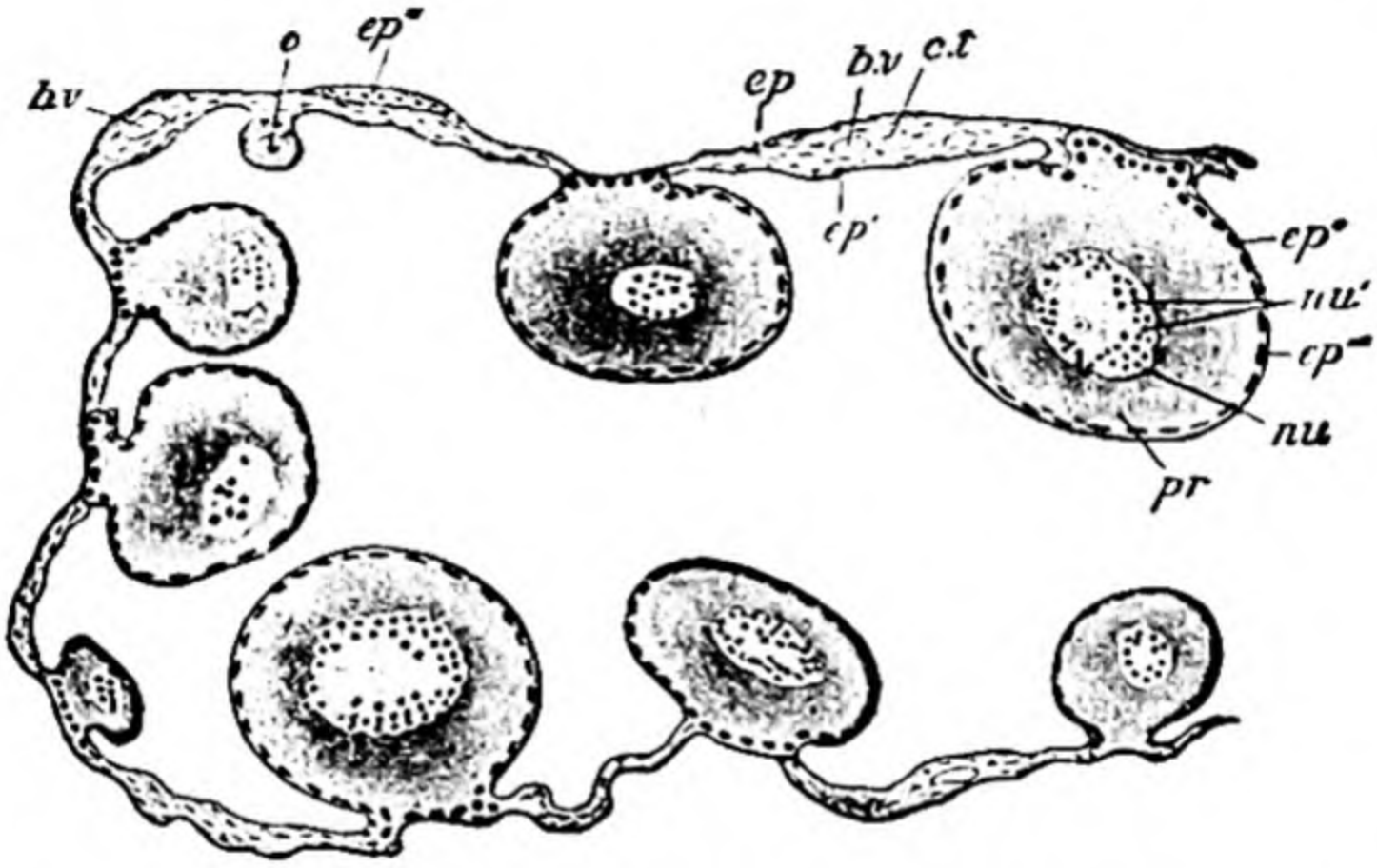


FIG. 65.—Transverse section of Frog's ovary. (× 30.)
b. v. blood-vessels; *c. t.* connective-tissue; *ep.* outer layer, and *ep'* inner layer of epithelium; *ep''*, outer layer of ovarian follicle, continuous with *ep'*; *ep'''*, germinal epithelium, derived from *ep.*; *ep''''*, follicular epithelium, derived from *ep.*; *nu.* nucleus of ovum; *nu'*, nucleoli; *o.* young ovum; *pr.* cytoplasm of ovum containing yolk-granules. (After Marshall.)

(Fig. 65) is a large globular cell with a clear nucleus (*nu*) containing numerous nucleoli (*nu'*), and having its cytoplasm (*pr*) full of *yolk-granules*—grains of protein and fatty material which serve as nutriment for the growing embryo. It becomes covered with a delicate egg-membrane. By the time the egg is mature a superficial deposit of pigment takes place over the hemisphere which is relatively free from yolk granules.

In the young condition all the epithelial cells forming the walls of the ovary are alike, but as the organ reaches maturity, certain of them (*o*) enlarge and give rise to the ova, while others form an investment or *follicle* (*ep''''*) for each ovum.

The oviduct (Fig. 5, *l. ovd*, *r. ovd*), as you have seen, is a long and greatly convoluted tube lying dorsal to the ovary. Its anterior end narrows considerably, runs parallel with the gullet, passes to the outside of the root of the lung, and then opens into the cœlome by a small aperture (*r. ovd'*). The greater part of the oviduct is about as wide as the small intestine, and is thick-walled and lined with gland-cells, which secrete the jelly surrounding the eggs when laid (p. 10). Posteriorly it suddenly dilates into a wide, thin-walled chamber (*r. ovd''*) which opens into the dorsal wall of the cloaca. Notice that there is thus no connection between the generative organs and the kidneys in the female such as occurs in the male, the ureters serving as renal ducts only.

In the breeding season, which lasts throughout the summer, the ovarian follicles rupture and set free the eggs into the cœlome, whence by some means or other they find their way into the small openings of the oviducts, and so into these tubes, where each becomes surrounded by a little sphere of jelly secreted by its gland-cells. Passing down the oviducts the eggs accumulate in the dilated extremities, which they distend enormously, so that, just before laying, the abdomen of a female frog is nearly filled by these two great egg-reservoirs; the ovaries, having lost so many of their eggs, are correspondingly reduced in size.

Fertilization.—During copulation the eggs are laid, and immediately the spawn is passed from the oviducts of the female into the water, the male sheds over them a quantity of spermatic fluid (p. 10). The sperms, swim-

ming actively through the water, enter the spheres of jelly and come into contact with the eggs. A single sperm then penetrates the egg-membrane of an ovum, loses its tail, and its head coming into contact with the nucleus of the egg, fuses or *conjugates* with it, so that a single nucleus is formed by the union of the egg-nucleus with the sperm-nucleus. The details of this process, as also of the development of the sperms and the maturation of the ovum, will be found in Part III, but can be left out of consideration for the present. We may speak of conjugating cells in general as *gametes*, the sperm in this case being the male gamete, and the ovum the female gamete, the body formed by the fusion of two gametes being known as a *zygote*.

This process is known as *fertilization* or *impregnation*. Without it, as we have seen, the egg is incapable of development; after it has taken place, the egg—or more strictly, the *oosperm*, since it is now an ovum *plus* a sperm—is potentially a young frog, since, if left undisturbed in water, it will in course of time give rise to a tadpole, which in its turn will change into a frog.

It must be remembered in the first place that the fertilized egg is a single cell, comparable with a blood-corpuscle or an epithelial cell. It is, however, peculiar in two respects; first in having its nucleus derived in part from a sperm, so as to contain matter from both the male and the female parent; and secondly in having its cytoplasm distended with yolk-granules to such an extent that, instead of being a minute body visible only under the microscope, it is easily visible to the naked eye. The yolk is not equally distributed: in one hemisphere it is less abundant than elsewhere, and it is this more protoplasmic hemisphere which is superficially blackened by a layer of pigment, and which always floats upwards in the water when the egg is laid.

Segmentation of the Oosperm.—Almost directly after being laid and fertilized the egg undergoes a remarkable change. A furrow appears all around it, as if made with a blunt instrument, and deepening gradually, at last divides the oosperm into two hemispheres in contact with one another by their flat faces (Fig. 66, A). The examination of sections shows that this process is preceded by the division of the nucleus into two; its final result is the division of the originally one-celled egg into two cells or *blastomeres*. Now if you refer to Chapter VIII, you will be reminded of the fact that the epithelial cells of the skin multiply by a similar process of *simple fission*, or division into two; the nucleus in each case dividing first, and afterwards the cytoplasm.

The furrow which effects this division of the oosperm passes through both black and white poles, so that each of the two cells formed is half black and half white. Soon a second furrow is formed at right angles to the first, being, like it, meridional, *i.e.*, passing through the poles (Fig. 66, B). It divides what we must now call the *embryo* into four cells, each half black and half white. A third furrow is then formed, passing round the equator, but nearer the black than the white pole (C). It therefore divides the embryo into eight cells, four upper black and four lower white, the latter being obviously the larger.

This process of division or *segmentation of the oosperm* continues, the black cells dividing more rapidly than the white, so that before long the embryo consists of a mass of cells, the *polyplast*, somewhat resembling a mulberry, and therefore often called a *morula*, one hemisphere being composed of small cells containing much cytoplasm, and little yolk, and externally pigmented (D—F, *mi*), and the other of larger cells containing less cytoplasm and much yolk, and not pigmented (*mg*). As

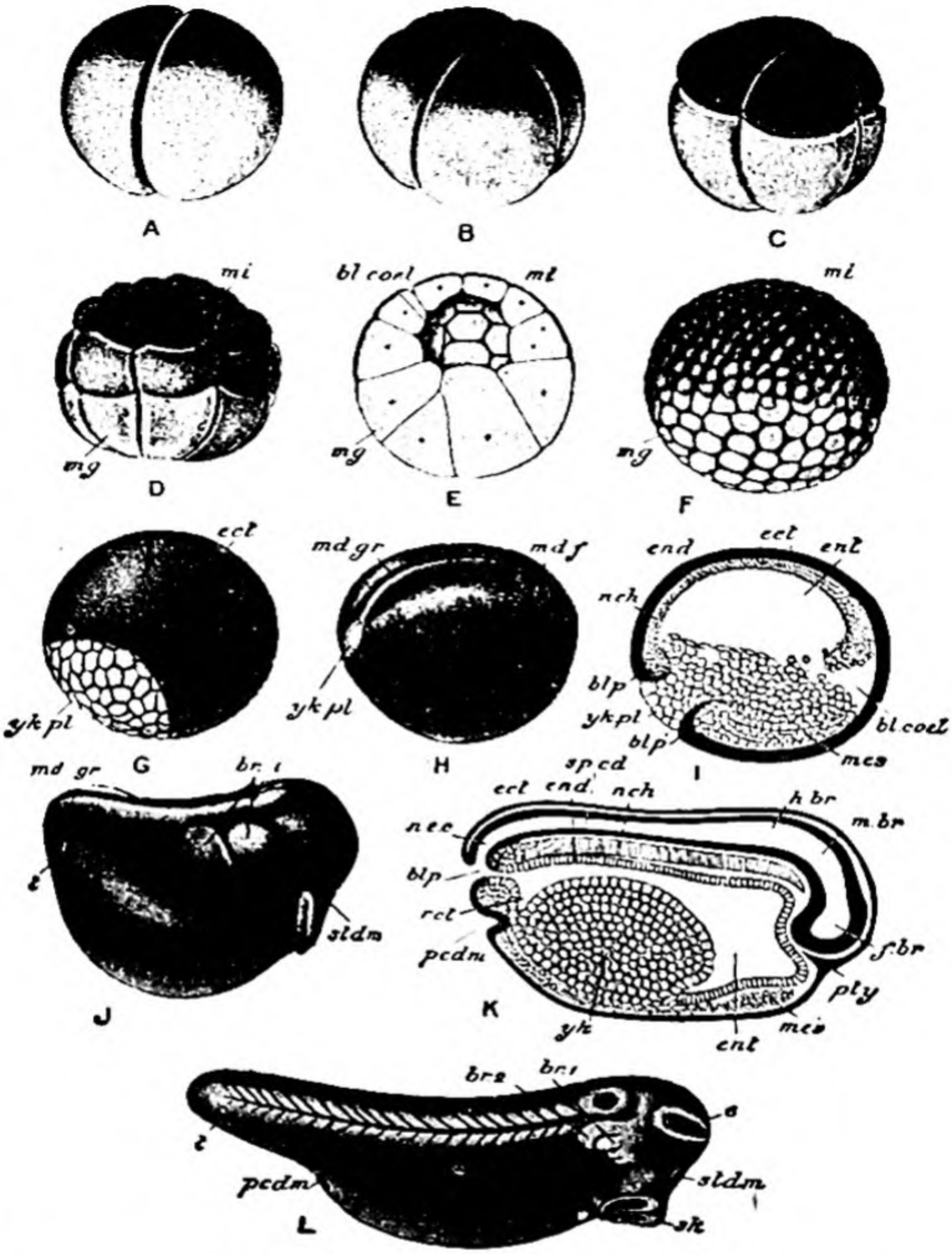


FIG. 66.—Development of the Frog.

A—D, segmentation; E, the blastula stage, bisected vertically to show the segmentation-cavity; F—H, overgrowth of ectoderm; I, longitudinal vertical section, just below the disappearance of the segmentation-cavity, showing the establishment of the germinal layers; J, assumption of tadpole-form; K, longitudinal vertical section, showing the establishment of nervous system, notochord, and alimentary canal; L, newly hatched tadpole. (× 10.)

bl. cœl. segmentation cavity; *blp, blp'*, blastopore; br^1, br^2, gills; *br. a.* branchial arches; *e*, eye; *ect.* ectoderm; *end.* endoderm; *ent.* enteron; *f. br.* fore-brain; *h. br.* hind-brain; *m. br.* mid-brain; *md. f.* medullary fold; *md. gr.* medullary groove; *mes.* mesoderm; *mg.* large lower cells; *mi.* small upper cells; *nch.* notochord; *n. e. c.* neurenteric canal; *pcdm.* proctodæum; *ply.* invagination of ectoderm which will form the pituitary body; *rct.* rudiment of rectum; *sk.* sucker; *sp. cd.* spinal cord; *stdm.* stomodæum; *t.* tail; *yk.* yolk-cells; *yk. pl.* yolk-plug which fills the blastopore. (From Parker and Haswell's *Zoology*. A—D F—H, and J from Ziegler's models. E, I, K, and L after Marshall.)

segmentation goes on, a cavity appears in the interior of the embryo; it is called the *segmentation-cavity* (E, *bl. cæl*), and is due to the fact that the work of segmentation produces a waste of substance which there is at present no means of making good, so that for a time, while the size of the embryo remains the same, its bulk diminishes, some of its substance being used up; in other words, it feeds on itself.

Segmentation now proceeds to such an extent that the black cells become too small to be seen except with a lens of tolerably high magnifying power, so that with the amount of magnification used in Fig. 66, G, the black hemisphere shows no division into cells. At the same time the black hemisphere gradually encroaches on the white until only a small circular space—the *blastopore*, filled by a mass of yolk-cells—the *yolk-plug*, is left uncovered (G, H, *yk. pl.*).

Development of the Chief Organs.—In the meantime a second cavity appears in the interior of the embryo, and as it increases in size, the segmentation-cavity undergoes a proportional diminution and finally disappears. This new cavity, or *enteron* (Figs. 66, I, and 67, *ent*), is the rudiment of the alimentary canal: it begins to be formed as a narrow slit at the edge of the blastopore through which it at first communicates with the exterior, but it soon becomes closed: at present there is neither mouth nor anus.

By this time the cells of which the embryo is composed have assumed different forms and become arranged in a very definite manner. First of all there are several layers of small pigmented cells, derived from the black cells of earlier stages, which cover the whole embryo with the exception of the yolk-plug: these constitute the *ectoderm* (Fig. 66, G, H, I, *ect*). Forming the roof of the enteric cavity are other layers of cells derived from

the yolk-cells of earlier stages and forming the *endoderm* (I, *end*) : the floor of the enteron is at present formed of unaltered yolk-cells. Between the ectoderm and the yolk-cells on the lower pole are several layers of small cells which gradually spread until they form a complete layer between the ectoderm and the endoderm : these constitute the *mesoderm* (I, *mes*). The ectoderm, endo-

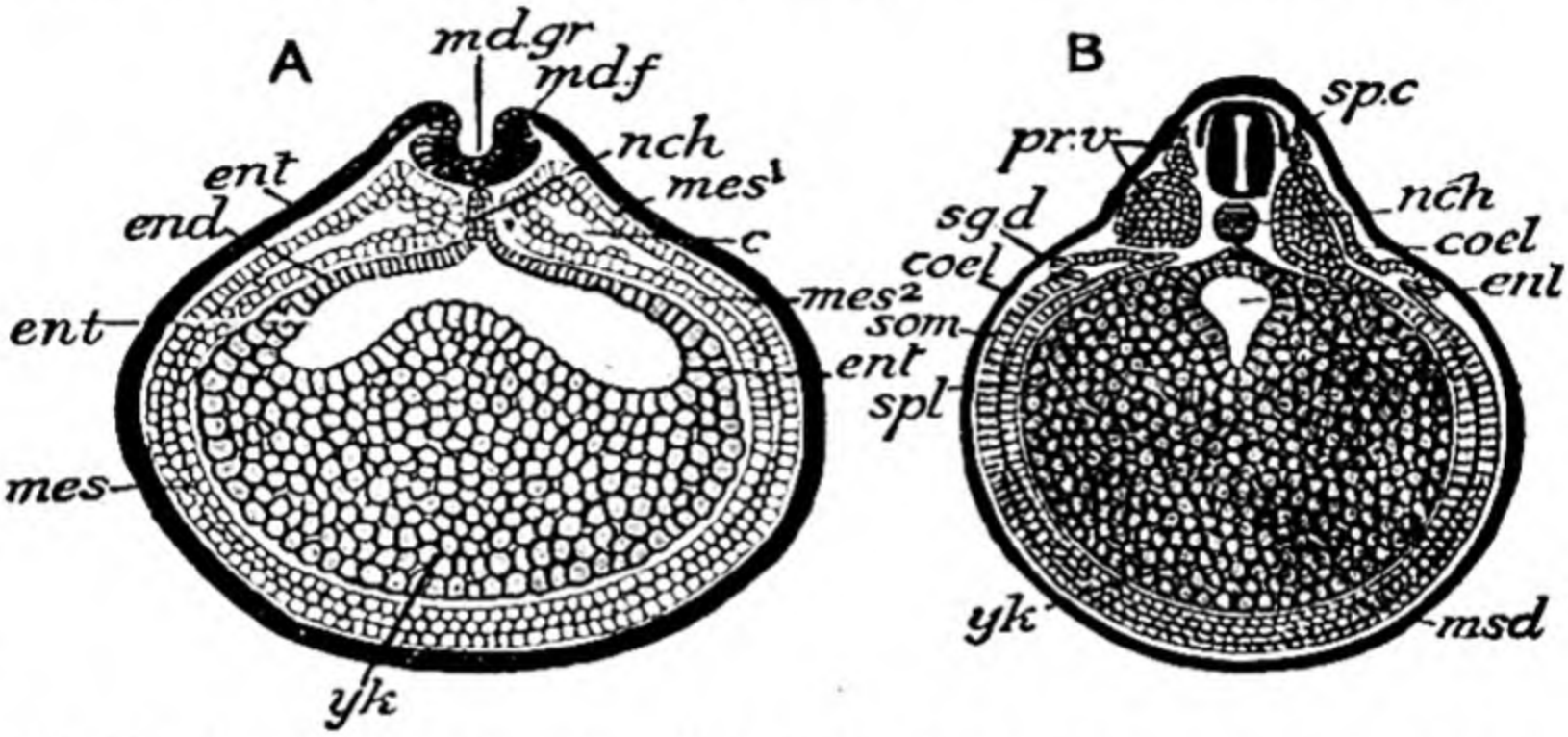


FIG. 67.—Transverse sections through the body of a Frog embryo. A, with open medullary groove (compare Fig. 66, J). B, with closed medullary groove (compare Fig. 66, L.) (× about 30.)

c, *coel*. cœlome; *coel*¹. prolongation of cœlome into mesodermal segments (*pr. v*); *end*. endoderm; *ent*. enteron; *mes*. *msd*. mesoderm; *mes*¹, *som*. outer parietal layer of mesoderm; *mes*², *spl*. inner visceral layer of mesoderm; *md. f*. medullary fold; *md. gr*. medullary groove; *nch*. notochord; *pr. v*. mesodermal segment; *sg. d*. primary kidney duct (pronephric duct); *sp. c*. medullary cord; *yk*. yolk-cells. (After Marshall.)

derm, and mesoderm are known as the three embryonic tissues or *germinal layers*.

While these processes have been proceeding, a longitudinal groove appears on the dorsal surface of the embryo : this is the *medullary* or *neural groove*, and is bounded by a pair of *medullary folds* (Figs. 66, H, J, and 67, *md. gr*, *md. f*). The medullary groove extends backwards to the blastopore, which now marks its posterior end. As development goes on, the folds approach one another and unite, so as to convert the groove into a

canal; the cells lining this canal give rise to the central nervous system (Fig. 66, K; compare Part III, Chapter II), and its cavity becomes the central canal of the spinal cord and the ventricles of the brain. The anterior end of the hollow *medullary cord* thus developed enlarges to form three vesicles, one behind the other, and known respectively as the *fore-brain*, *mid-brain*, and *hind-brain*, each containing a ventricle. The fore-brain eventually gives rise to the diencephalon and to the cerebral hemispheres, produced in front into the olfactory lobes; the mid-brain to the optic lobes and crura cerebri; and the hind-brain to the medulla oblongata and cerebellum. It will be seen (Fig. 67) that the medullary groove is lined by ectoderm and that therefore the whole central nervous system is ectodermal in origin; and this is also true of the nerves.

A longitudinal thickening of the endoderm on the dorsal side of the enteron becomes constricted off as a solid rod of cells, lying between the medullary cord and the enteron and extending from the blastopore to the region of the pituitary body. This is the *notochord* (Figs, 66, K, and 67, *nch*); it forms the primary axial skeleton around which the vertebral column is subsequently developed. The mesoderm is for some time a solid mass occupying all the space between the ectoderm and endoderm, so that there is no body-cavity. But at a later stage a cavity appears dividing the mesoderm into two layers, one in contact with the ectoderm (*parietal layer*, Fig. 67, *mes*^{1}, *som*), the other with the endoderm (*visceral layer*, *mes*^{2}, *spl*). The space between them is the *cœlome* (*c*, *coel*). The dorsal part of the mesoderm on either side of the medullary cord and notochord becomes divided transversely, and gives rise to muscle-segments or *myomeres* (Figs. 66, L, and 67).

The embryo soon begins to elongate in a definite direc-

tion (Fig. 66, J) : its dorsal surface, still marked by the medullary groove, which now soon becomes closed, is slightly concave, its ventral surface very convex. The blastopore closes up, the yolk-plug becoming entirely covered by ectoderm ; but for a short time the medullary canal and enteron still communicate by the *neurenteric canal* (K, *n.e.c.*) This soon disappears, and at the hinder end of the embryo a conical outgrowth forms the rudiment of the tail (*t*). The opposite end is rounded, and on its ventral surface appears a little half-moon-shaped groove, the rudiment of the sucker by which the tadpole attaches itself to weeds (J and L, *sk*) ; this afterwards becomes subdivided into two (Fig. 68, C). Just above the sucker a depression—the mouth-pit or *stomodæum* (L, *stdm*)—makes its appearance, and is the first indication of the mouth. A similar depression below the tail—the *proctodæum* (K and L, *pcdm*)—marks the anus : both at first are mere blind pouches and have no communication with the enteric cavity. The head-region is further marked by two pairs of vertical ridges separated by depressions : the ridges are the *branchial* or *gill arches* (J, *br. a*), and the depressions the *branchial clefts*.

Further elongation takes place (Fig. 66, L), the head becomes distinctly marked off, the tail extends considerably beyond the anus, a thickening appears which marks the position of the eye (*e*), and a depression that of the ear (just above br^2 in the figure) ; and from each branchial arch arises a little tuft, the rudiment of one of the *external gills* (br^1, br^2). In this condition the tadpole is hatched : it is still unable to feed, the stomodæum not yet being in communication with the enteric cavity ; it is nourished therefore entirely by the yolk with which a large portion of the body is still filled.

Up to the stage shown in Fig. 66, I, the cells of which

the tadpole is composed, although distinguishable into ectoderm, endoderm, and mesoderm, are all more or less similar: there are no muscles, no cartilages, bones, or connective-tissue. But shortly after the stage referred to, the permanent tissues begin to be differentiated: the outer ectoderm cells take on the form of epidermis, the endoderm cells become the epithelium of the enteric canal, and from offshoots of the latter—all of course lined by endoderm—are formed the lungs, the liver, the pancreas, and the urinary bladder.

The mesoderm undergoes much more extensive changes, giving rise to the connective-tissue, cartilage, bone (after the metamorphosis of the tadpole larva is completed) and muscle, as well as to other parts—*i.e.*, to by far the greater portion of the permanent tissues. In certain places the embryonic mesoderm cells, hitherto in close contact, separate from one another and become branched, while between them appears intercellular substance with fibres crossing one another in various directions: in this way the connective-tissue of the adult body is produced.

The various parts of the skeleton first arise by the conversion of portions of the mesoderm into cartilage. The cells retreat from one another and between them a clear substance, the matrix, makes its appearance. For a considerable time almost the whole skeleton consists of cartilage, but after metamorphosis much of this tissue is replaced by bone developed from a layer of cells on the inner surface of the perichondrium. The bones thus formed to take the place of cartilages are *replacing bones*: *investing bones* arise in connective-tissue which has no direct relation to the cartilage (compare p. 41).

In the place where the voluntary muscles are to appear the mesoderm cells elongate, their nuclei multiply by fission, and their cytoplasm gradually becomes con-

PART II

CHAPTER I

PHYLUM PROTOZOA

AMŒBA: CLASS SARCODINA

FROM your study of the frog you will have learnt some of the more important facts with regard to the morphology and physiology of a comparatively highly organized animal, and will have overcome a number of preliminary difficulties in acquiring a knowledge of zoological terminology and technique. You will now, therefore, be in a better position to undertake a systematic and comparative examination of a number of other animals—some much less complicated, some more complicated, than the frog—working upwards from the simple to the complex forms. In doing so, you must continually bear in mind the deductions in connection with the theory of evolution referred to in the previous chapter.

Amœba.—Let us begin with a very instructive animalcule usually known as *Amœba proteus*.[1] Amœbæ are often found in the slime at the bottom of pools of stagnant water, adhering to weeds and other submerged objects.

[1] Certain authorities think that the correct zoological name of the species is *Chaos diffluens*. Another giant amœba which has been recently re-discovered in America is *Chaos chaos* originally described by Linnæus in 1767. It is visible to the naked eye and attains in locomotion the remarkable length of 2 to 5 millimetres.

They are mostly invisible to the naked eye, rarely exceeding $\frac{1}{4}$ of a millimetre ($\frac{1}{100}$ inch) in diameter, so

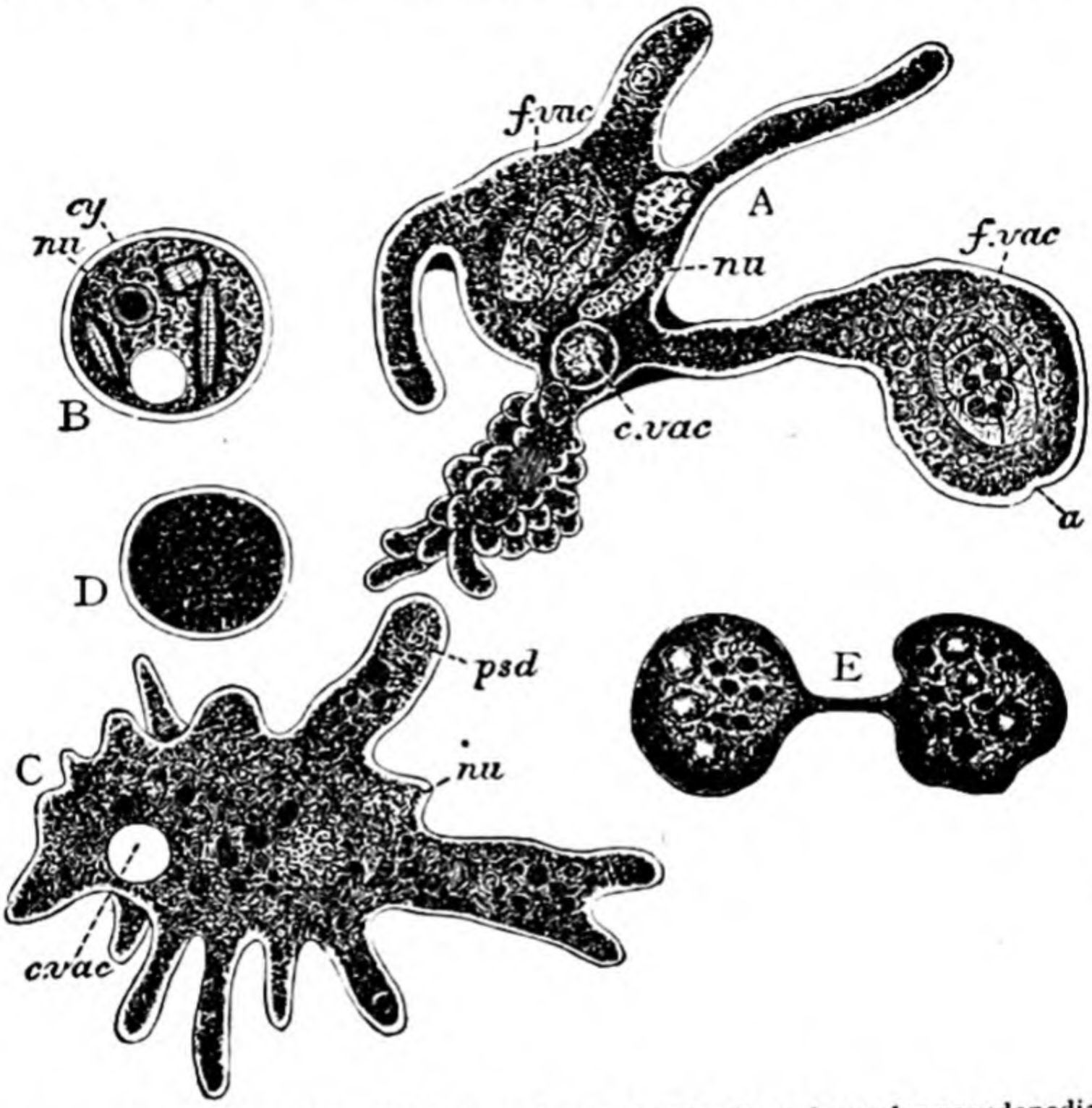


FIG. 72.—A, *Amœba proteus*, a living specimen, showing large irregular pseudopodia, nucleus (*nu*), contractile vacuole (*c. vac*), and two food-vacuoles (*f. vac*), each containing a small ciliate (see Chapter III) which has been ingested as food. The letter *a* to the right of the figure indicates the place where two pseudopods have united to enclose the food vacuole. The contractile vacuole in this figure is supposed to be seen through a layer of granular protoplasm, whereas in B and C it is seen in optical section, and therefore appears clear. (× about 300.)

B, an encysted Amœba, showing the cyst (*cy*), nucleus (*nu*), clear contractile vacuole, and three microscopic plants (diatoms) ingested as food.

C, *Amœba proteus*, a living specimen, showing several large pseudopods (*psd*), single nucleus (*nu*) and contractile vacuole (*c. vac*), and numerous food-particles embedded in the granular endoplasm. (× 330.)

D, nucleus of the same after staining, showing a ground substance containing deeply-stained granules of chromatin, and surrounded by a distinct membrane. (× 1010.)

E, *Amœba proteus*, in the act of multiplying by binary fission. (× 500.)

(From Parker's *Biology*: C and D after Gruber; A and E after Leidy; B after Howes.)

that it is necessary to examine them entirely by the aid of the microscope. Though they can be seen and recognized with the low power, the high power is necessary for the accurate examination of their structure.

Anatomy.—Examined under the high power (Fig. 72), the Amœba appears like a little shapeless blob of jelly, nearly or quite colourless, and closely resembling a colourless blood-corpuscle or leucocyte of one of the higher animals (p. 98). The central part of it, or *endoplasm*, is granular and semi-transparent—something like ground-glass—while surrounding this inner mass is a border of perfectly transparent and colourless substance —the *ectoplasm*.

One very noticeable thing about the Amœba is that, like the leucocyte, it is never of quite the same form for long together, owing to the protrusion of *pseudopodia* (*psd*), by means of which it creeps along slowly. The occurrence of *amœboid movements* is alone sufficient to show that it is an *organism*, or living thing, and no mere mass of dead matter. Moreover, it consists of *cytoplasm*, and a *nucleus*[1] (A—D, *nu*) containing *chromatin* which is rendered more apparent by staining. The Amœba is therefore a *cell* (compare pp. 99 and 101).

A very important difference is thus at once seen between the Amœba and the frog: the Amœba is *unicellular—i.e.*, it consists of a single cell—while the frog is, as we have seen, a *multicellular* animal, built up of innumerable cells which are differentiated to form various tissues and organs.

Besides the nucleus, there is another structure frequently visible in the living Amœba and not present in

[1] Instead of containing one nucleus *Chaos chaos* possesses a large number, as many as one thousand or more in some individuals. It also possesses three or four to about a dozen contractile vacuoles.

the leucocyte. This is a clear, rounded space in the protoplasm (*c. vac*), which periodically disappears with a sudden contraction and then slowly reappears, its movements reminding one of the beating of a minute colourless heart. It is called the *contractile vacuole*, and consists of a cavity containing a watery fluid.

Physiology.—We must now study the physiology of our animalcule. First of all, as we have already seen, it is *contractile* : although it has no muscles, it can move about from place to place. Its movements, like the voluntary movements of the frog (pp. 8, 156), may occur without the application of any external stimulus, *i.e.*, they are *spontaneous* or *automatic* ; or they may be induced by external stimuli—by a sudden shock or by coming in contact with an object suitable for food. Movements of this latter kind, like those resulting from the stimulation of the nerves in a brainless frog, are the result of the *irritability* of the protoplasm ; the animalcule is therefore both automatic and irritable, although it possesses neither nerves nor sense-organs.

Under certain circumstances an Amœba temporarily loses its power of movement, draws in its pseudopods, and becomes a globular mass around which is formed a thick, shell-like coat, called the *cyst* (Fig. 75, B, *cy*). This is formed by the protoplasm by a process of *secretion* (p. 116) ; its composition is not known ; it is certainly not protoplasmic, and very probably consists of some nitrogenous substance allied in composition to horn and to the *chitin* (see Chapter VII) which forms the external shell of crustaceans, insects, &c.

The formation of the cyst is of great importance in preserving the animalcule from destruction by drought, so that should the pool in which it is living dry up, it may still remain alive, protected by its shell-like case, until the conditions for its active life are once more

restored. When favourable conditions return, encysted amœbæ which have been floating about in the air as particles of dust, settle on water, and escape by the rupture of their cysts. Encystment also serves to aid in the dispersal of the species.

Very often an Amœba in the course of its wanderings comes in contact with a still smaller organism of some kind or other. When this happens the Amœba may be seen to extend itself round the smaller organism until the latter becomes sunk in its protoplasm in much the same way as a marble might be pressed into a lump of clay or a drop of honey or treacle flow round an ant (Fig. 72, A, *a*). The diatom or other organism becomes in this way completely enclosed in a cavity or *food vacuole* (*f. vac*), which also contains a small quantity of water necessarily included with the prey. The latter is taken in by the Amœba as food: so that the Amœba, like the frog, *feeds*. It is to be noted that the reception of food takes place in a particular way, viz., by *ingestion—i.e.*, it is enclosed entire by the organism.

When the prey is thus ingested, its protoplasm becomes *digested*, any insoluble portions being passed out or *egested*, as fæces (pp. 9 and 71), from the surface of the Amœba as it creeps slowly on. Note that all this is done without either ingestive aperture (mouth), digestive cavity (stomach), or egestive aperture (anus): the food is simply taken in by the flowing round it of protoplasm, digested as it lies enclosed in the protoplasm, and those portions for which it has no further use are got rid of by the Amœba flowing away from them.

We have seen that the frog possesses certain digestive glands, the function of which is to secrete *digestive fluids* which have an important chemical action on the food swallowed, rendering it soluble and diffusible before it passes through the epithelial cells of the alimentary canal

into the blood: the gastric juice, for example, has the power of converting proteins into peptones by means of the ferment pepsin (p. 70); the digestion here takes place *outside* the cells, *i.e.*, is *extracellular*. There can be little doubt that the protoplasm of Amœba is able to render that of its prey soluble and diffusible by the agency of some substance analogous to pepsin, and that the dissolved matters diffuse through the body of the Amœba until the latter is, as it were, soaked through and through with them. The process of digestion in Amœba thus takes place within a single cell, *i.e.*, it is *intracellular*.

It has been proved by experiment that proteins are the only class of food which Amœba can make use of: it is unable to digest either starch or fat (p. 68). Mineral matters must, however, be taken with the food in the form of a weak watery solution, since the water in which the animalcule lives is never absolutely pure.

The Amœba being thus permeated, as it were, with a nutrient solution, the elements of the solution, hitherto arranged in the form of peptones, mineral salts, and water, become rearranged in such a way as to form new particles of living protoplasm, which are deposited among the pre-existing particles. In a word, the food is *assimilated*, or converted into the actual living substance of the Amœba, which must therefore grow, if nothing happens to counteract this formation of new protoplasm.

We have seen, however, that work results in a proportional amount of waste (p. 62), and just as in the frog or in ourselves, every movement of the Amœba, however slight, is accompanied by a proportional oxidation or low temperature combustion of the protoplasm, *i.e.*, the constituents of the protoplasm combine with oxygen, forming waste or excretory matters—carbon dioxide,

water, and certain nitrogenous substances of simpler constitution than proteins, such as urea. These products of *excretion*, formed in the case of Amœba without the agency of any special excretory organs (*e.g.*, kidneys), are given off partly from its general surface, but partly, it would seem, by the agency of the contractile vacuole, by means of which the excess of water taken in with the food is also got rid of.

With this breaking down of proteins the vital activities of all organisms are invariably connected. Just as useful mechanical work may be done by the fall of a weight from a given height to the level of the ground, so the work done by the organism is a result of its complex proteins falling, so to speak, to the level of simpler substances. In both instances potential energy or energy of position is converted into kinetic or actual energy.

The statement just made that the protoplasm of Amœba constantly undergoes oxidation presupposes a constant supply of oxygen. The water in which the animalcule lives invariably contains that gas in solution, and diffusion takes place, oxygen passing into the interior of the Amœba while carbon dioxide passes out into the water. This is the process of breathing or *respiration* (p. 127), and it occurs in Amœba without the agency of special respiratory organs.

We thus see that a very elaborate series of chemical processes is constantly going on in the interior of Amœba, as in the frog; the whole series is spoken of collectively as *metabolism—constructive* and *destructive* (p. 132). Living protoplasm is the most unstable of substances; it is never precisely the same thing for two consecutive seconds; its existence, like that of a waterfall or a fountain, depends upon the constant flow of matter into it and away from it.

It follows from what has been said that if the income of an Amœba, *i.e.*, the total weight of substances taken in (food *plus* oxygen *plus* water) is greater than its expenditure or the total weight of substances given out (fæces *plus* excreta proper *plus* carbon dioxide), the animalcule will grow : if less it will dwindle away : if the two are equal it will remain of the same weight or in a state of physiological equilibrium.

Reproduction.—It is evident that Amœba must also be able to perform the function of *reproduction*. You have learnt that the cells of the frog multiply by *simple* or *binary* fission (p. 99) : the nucleus first divides into two, and then the surrounding protoplasm ; and precisely the same thing occurs in Amœba (Fig. 72, E), the reproduction of which therefore takes place by the simplest method known, without any special reproductive organs. The animalcule simply divides into two Amœbæ, each exactly like itself, and in doing so ceases to exist as a distinct individual. Instead of the successive production of offspring from an ultimately dying parent, we have the simultaneous production of offspring by the division of the parent, which does not die, but becomes simply merged in its progeny. There can be no better instance of the fact that reproduction is discontinuous growth.

From this it seems that an Amœba, unless suffering a violent death, is practically " immortal," since it divides into two completely organized individuals, each of which begins life with half of the entire body of its parent, there being therefore nothing left of the latter to die : it therefore appears certain that " death has no place as a natural recurrent phenomenon " in that organism. In multicellular forms it is only the reproductive cells which are, physically, potentially immortal.

Some observers have found that occasionally two

Amœbæ come into contact and undergo fusion, just as the gametes of the frog (sperm and ovum) unite in the processes of fertilization (p. 177). This process of *conjugation* is followed by encystment and the production inside the cyst of a number of young Amœbæ by a process of *multiple fission*. It is important to bear in mind, however, that reproduction can take place quite independently of such a process.

Amœbæ may also be propagated artificially. If a specimen is cut into pieces, each fragment is capable of developing into a complete animalcule provided it contains a portion of nuclear matter, but not otherwise. From this it is obvious that the nucleus exerts an influence of the utmost importance over the vital processes of the organism.

If an Amœba does happen to be killed and to escape being eaten, it will, like a dead frog, undergo gradual decomposition, becoming converted into various simple substances of which carbon dioxide, water, and ammonia are the chief (p. 62).

Death results if the temperature to which an Amœba is exposed reaches about 40° C., and at freezing point its movements cease entirely and it becomes inert.

Class Sarcodina.—Amœba has been studied as one of the simplest types of unicellular animals, which are all placed in the phylum protozoa. The phylum comprises several classes, including Sarcodina, Flagellata, Ciliata and Sporozoa. Sarcodina are characterized by the body of the unicellular organism being devoid of a cuticle, and thus capable of flowing out into pseudopodia. These latter may be blunt finger-shaped processes as in Amœba, or drawn out into long fine threads, which may be stiff and radial in arrangement, or run into one another to form a network.

Certain forms closely related to Amœba live in the

alimentary canal or other organs of higher animals such as cockroach, frog, and man. They get their food ready made from the animals inside which they live, or even attack the tissues of the latter. Such organisms are known as *parasites*, and the animals harbouring them as their *hosts*. Parasitic amœbæ are placed in the genus *Entamœba*, and one of them, called *Entamœba histolytica*

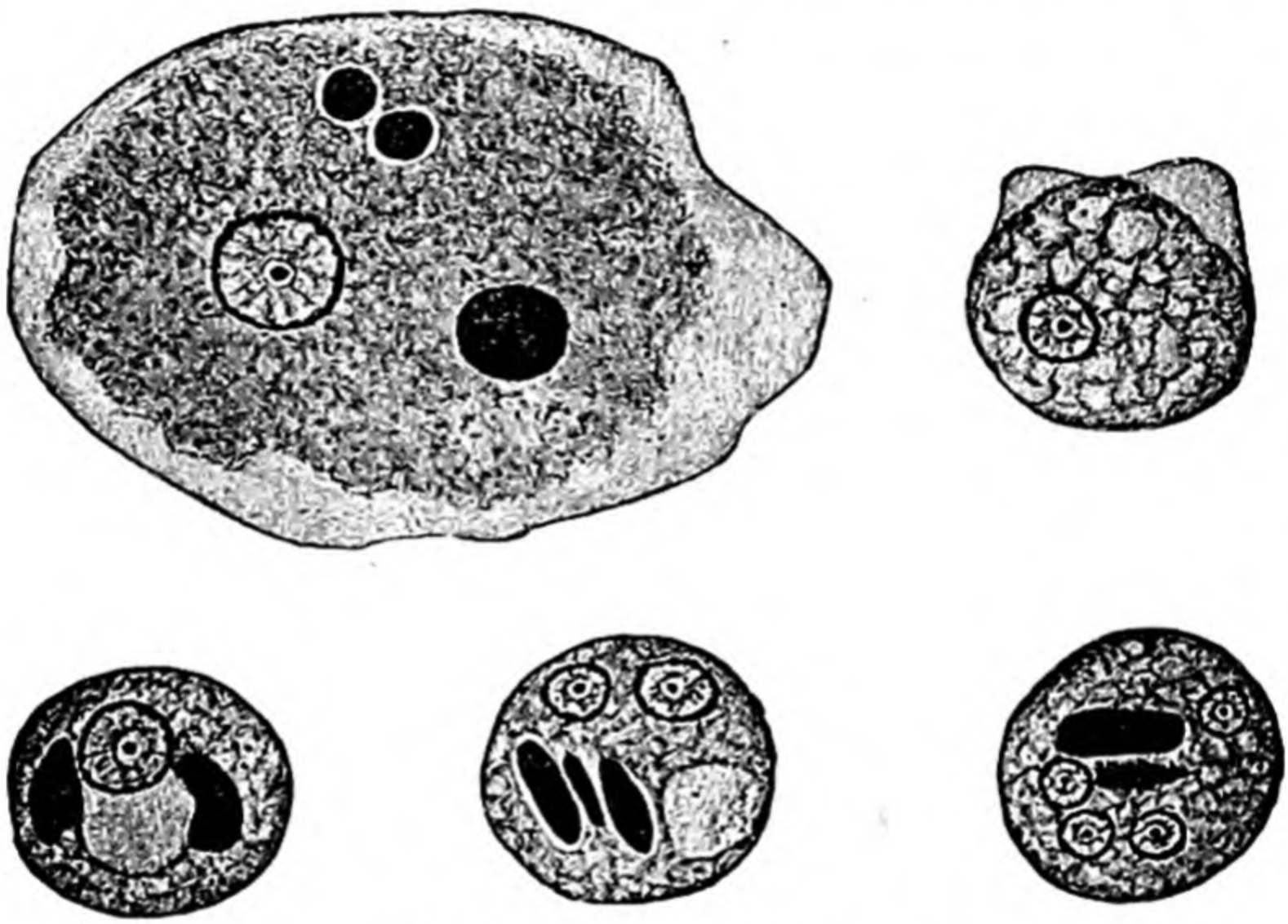


FIG. 73.—*Entamœba histolytica.*

A, large active form which has ingested three red blood-corpuscles; B, stage before encystment; C, D, E, cysts with one, two, and four nuclei respectively. (After Dobell, from Hegner and Taliaferro's *Protozoology*.)

(Fig. 73), is responsible for causing amœbic dysentery in man. The organisms invade the mucous and sub-mucous coats of the intestine, and, causing the rupture of the blood-capillaries in the latter, actually engulf the red blood-corpuscles (A). They may be carried by the blood-stream to other organs like the liver, and cause abscesses in that organ many years after the individual

had apparently recovered from the attack of dysentery. The organisms may also become encysted, and the cysts (C, D, E) may continue to live in the folds of the mucous membrane. These cysts are passed in the fæces of the host, and if they infect some article of food and get ingested by another person, the cysts may rupture and the active amœbæ set up an attack of dysentery in the latter. In this manner a person who has had an attack may serve as a *carrier* for a long time after apparent recovery.

All parasitic forms are not, however, dangerous. Another species, known as *Entamœba coli*, commonly occurs in the rectum of man, and, feeding upon the bacteria of putrefaction, serves as a harmless scavenger.

Belonging to the same class are beautiful forms, encased in shells of varied form and chemical composition. In some of them the shells are composed of calcium carbonate, and when the organisms die, the shells fall as a slow rain through miles of water to the floor of the deep sea, forming the ooze. Such deposits in the course of millions of years formed the chalk cliffs at Dover, which later must have been raised above the surface of the ocean. In another group the shells are made of silica, and under the microscope are seen to be some of the prettiest objects built by tiny architects.

CHAPTER II

PHYLUM PROTOZOA—*continued*

EUGLENA : VOLVOX : CLASS FLAGELLATA : DIFFERENCES BETWEEN ANIMALS AND PLANTS

THERE is a world of life in a drop of water. If you bring some water from the nearest pond or puddle, and carefully examine a drop under the microscope, you will find unicellular organisms of diverse form and structure. Some creep slowly by the aid of pseudopodia, others possess a more definite form and move with greater or less agility by the help of minute permanent organs of locomotion. Many different kinds of organisms will be seen to be provided with one or more fine whip-like processes or *flagella*, and a few of these we shall consider in this chapter. Others possessing minute, stiff, hair-like processes or *cilia* will be studied in the next chapter.

Euglena.—It is one of the commonest and one of the largest of these flagellate Protozoa, and will be encountered in puddles of rain-water containing decaying vegetable matter, if the water looks to be green and the green colour is not due to the presence of filamentous algæ which can be recognized by the naked eye on taking up some water in a glass tube or vessel. The green colour is imparted to the water by the presence of myriads of Euglenæ, which are green, as they contain bodies of a deep green colour. There are many species of *Euglena*, but we shall describe the one to which the name *Euglena viridis* has been given.

It is about $\frac{1}{250}$ of an inch in size, and oval in form, with one end bluntly truncated and the other pointed. The blunt end is always forward in locomotion, and so may be designated as anterior, the pointed end being referred to as posterior. The organism possesses a definite *cuticle* or *periplast*, which gives it a relatively fixed form as compared with Amœba. Arising from a conical depression at the anterior end is a long and extremely fine *flagellum*, which is seen to execute a series of rapid movements of bending and straightening, similar to the movements of a finger in beckoning. These movements of the flagellum cause the organism to progress forwards. On careful examination under highest powers of magnification, the single flagellum is seen to bifurcate and arise by two roots from the wall of the gullet (Fig. 74, B, *fl'*, *fl''*). Besides the movements of progression caused by the flagellum, the body of the organism also shows movements of contraction and expansion of its various parts, which are possible owing to the elasticity of the cuticle, and are described as *euglenoid movements*.

The cytoplasm is differentiated, as in Amœba, into ectoplasm and endoplasm. Near the anterior end are one or more small *contractile vacuoles* (*c. v.*) leading into a large non-contractile *reservoir* (*r.*), which empties itself into the gullet (*gul.*). Close to the inner end of the gullet is a bright red speck, the *stigma* (*st.*), formed of a pigment allied to chlorophyll and called hæmatochrome. The stigma is a light-perceiving organ, and is popularly referred to as the eye. In the posterior third of the body is situated a spherical *nucleus* (*nc.*), containing a central darker spot, the so-called nucleolus (*ncl.*), surrounded by a large number of chromatin particles.

The body appears to be uniformly green, only the anterior portion being colourless. When seen under a high power of the microscope, the green colour is found

to be due to the presence of a large number of oval, disc-shaped *chromatophores* (*ch.*), which are green owing

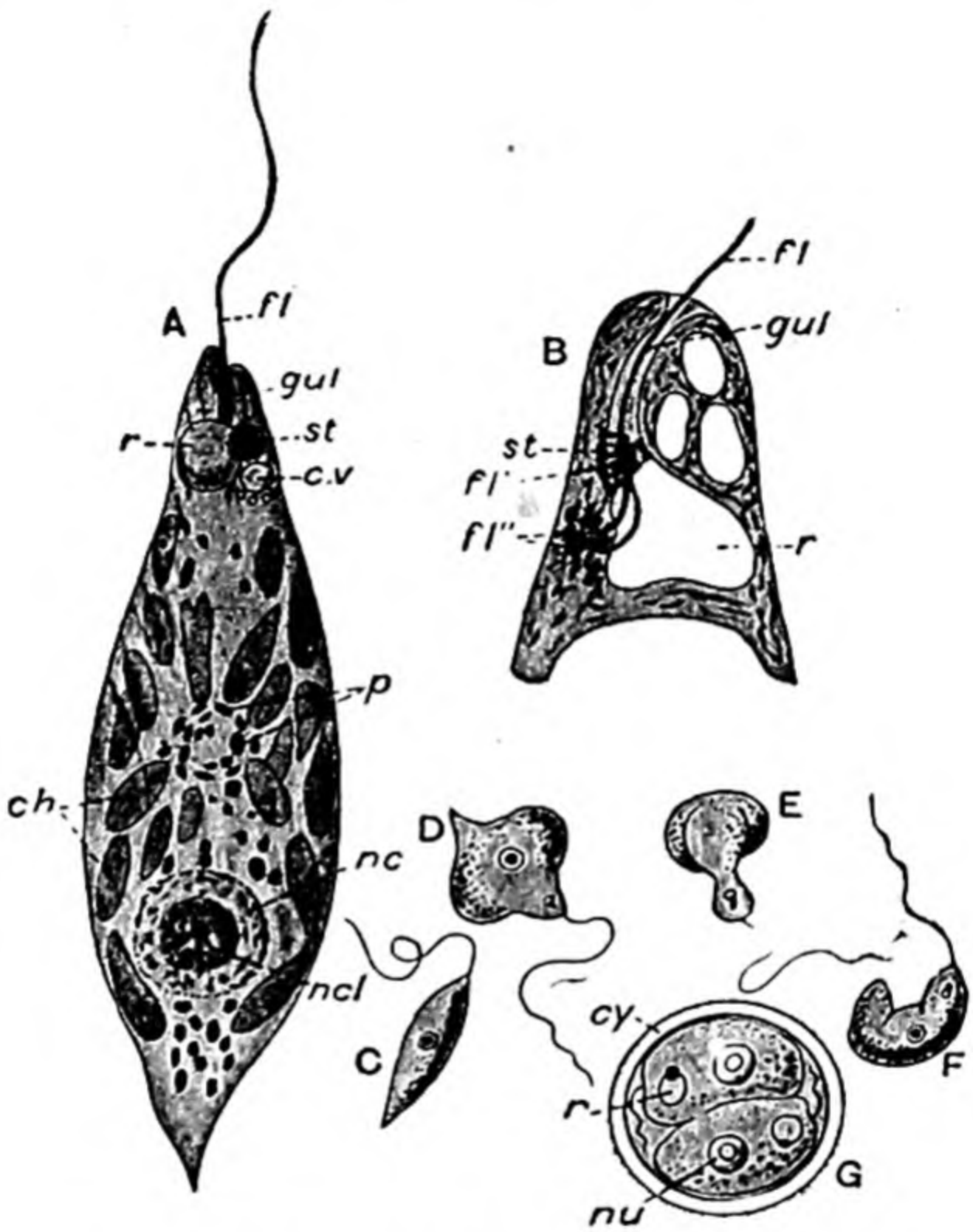


FIG. 74.—*Euglena viridis.*

A, entire organism magnified 1000 times; B, anterior end magnified 3000 times, showing origin of flagellum, etc.; C–F, showing euglenoid movements; G, encysted form showing binary fission.

Ch. chromatophores; *c.v.* contractile vacuole; *cy*, cyst; *fl.* flagellum; *fl'.* thickening on flagellum; *fl''*. two roots of flagellum; *gul.* gullet; *nc.*, *nu.* nucleus; *ncl.* " nucleolus "; *p.* paramylum bodies; *r.* reservoir; *st.* stigma.

(A, from Doflein; B, from Doflein after Wager; C–G, after Saville Kent.)

to their containing chlorophyll, the colouring-matter usually found in plants. In the more central region of

the body are to be seen a heap of rod-shaped granules of *paramylum* (*p.*), a carbohydrate allied to starch.

The nutrition of the organism is like a green plant. Through the agency of the green chromatophores, and with the help of sunlight, the carbon dioxide dissolved in the water is decomposed, setting free oxygen and combining carbon with the elements comprising water to form the carbohydrate paramylum. In bright sunlight the paramylum granules increase in size, but they diminish when Euglenæ are kept in the dark for some time. But, in addition to this characteristic vegetable (*holophytic*) mode of nutrition, it is possible that the organism also takes in solid particles of food in a characteristically animal (*holozoic*) manner. The movements of the flagellum create a whirlpool, by which minute organisms would be brought to the gullet and taken in as food. It is more probable that the organism supplements the *holophytic* mode of life by a *saprophytic* one—that is, by absorbing through the general surface the products of decaying organic matter dissolved in the water.

Sometimes the active movements of the organisms cease, and each individual encysts or surrounds itself with a cyst of cellulose (G). After remaining quiescent for some time, the organism may emerge and resume active life, or while in the encysted condition reproduction may take place. It multiplies by longitudinal *binary fission*, the plane of division passing through the long axis of the body. Sometimes *multiple fission* is known to occur inside a cyst, and a large number of flagellulæ are set free, which may pass through an amœboid stage, and develop into the adult form.

VOLVOX

Volvox.—It would be interesting to examine next an organism in which a large number of individual cells

or zooids remain adherent and form a many-celled spherical green colony. Each colony of *Volvox globator* is the size of a pin's head, and easily visible to the naked

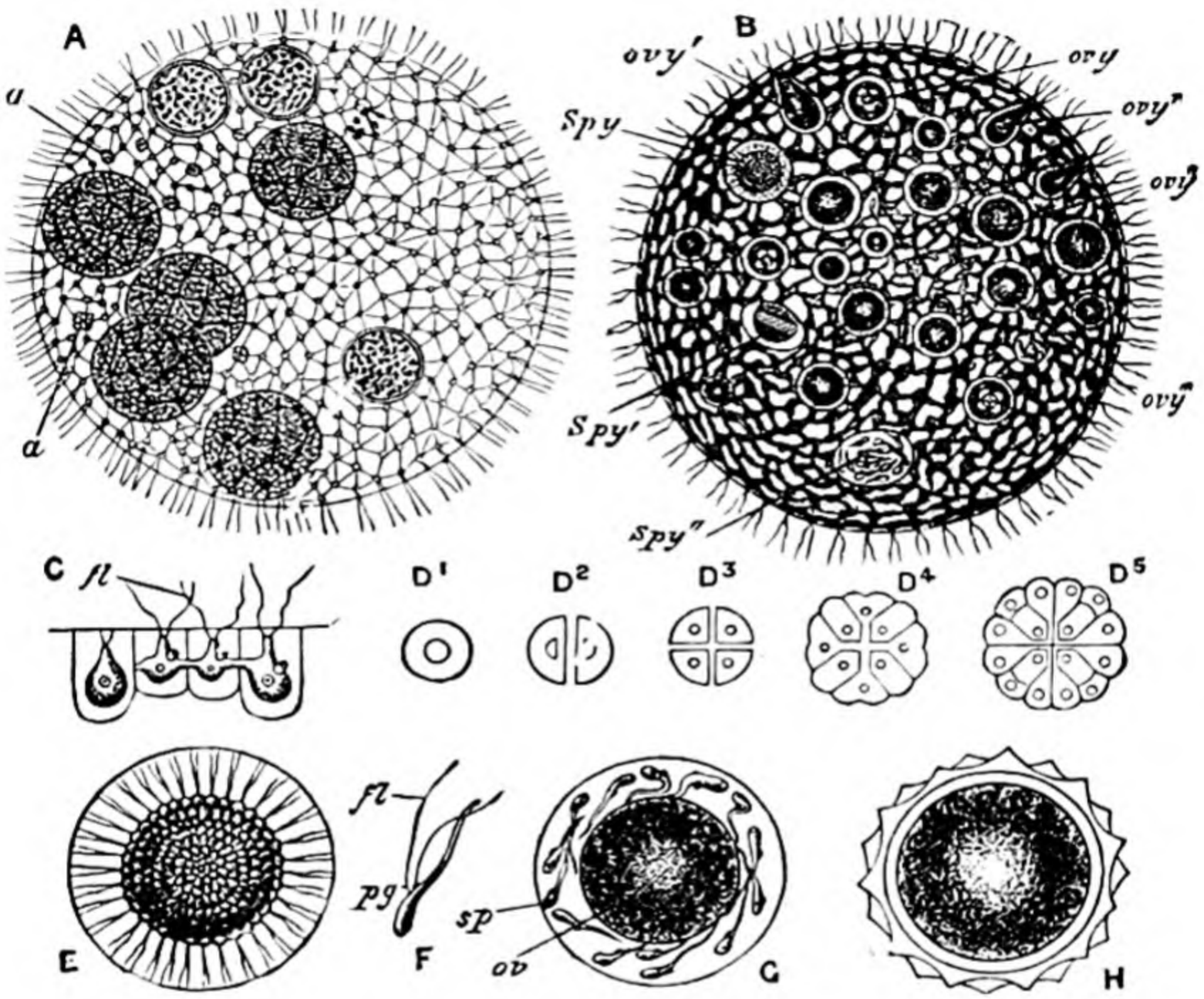


FIG. 75.—*Volvox globator*.

A, entire colony, enclosing several daughter-colonies; B, a colony during sexual maturity; C, four zooids in optical section; D^1–D^5, development of a zooid to form a daughter colony; E, ripe spermary; F, microgamete; G, macrogamete surrounded by a number of microgametes; H, zygote.

a. parthenogonidia or zooids which produce daughter-colonies; *fl*. flagellum; *ov*. ovum or macrogamete; *ovy*. ovaries each containing a single macrogamete; *pg*. pigment spot; *sp*. sperm or microgamete; *spy*. spermaries.

(From Parker's *Biology*, after Cohn and Kirchner.)

eye as it rotates in the stagnant water brought from a pond or ditch. It has the form of a hollow sphere, the wall of which consists of a jelly-like material in which 10,000 cells or more lie embedded (Fig. 75, A). Every

cell has its own cell-wall or envelope, separated from the cytoplasmic body by a considerable space (Fig. 75, C), and, being pressed against the envelope of neighbouring cells, acquires a hexagonal outline. The cytoplasmic bodies of adjacent cells are connected together by fine processes of protoplasm. Every individual cell has a nucleus, a contractile vacuole, a chromatophore, and a pair of flagella, which last project from the surface of the colony, and, along with the flagella of the other cells, serve to bring about the movement of the colony as a whole. Each cell is thus the equivalent of a single Euglena. These ordinary cells can multiply by division and increase the number of total cells in the colony, but they cannot give rise to new colonies.

The formation of new colonies takes place in one of two ways. Certain cells or zooids are set apart in the colony, which can be distinguished by their larger size and absence of flagella. Each of these zooids divides by a process of asexual reproduction resembling the segmentation of the egg in the higher animals (D^1–D^5), and forms a daughter-colony. The daughter-colonies become detached and swim freely in the interior of the mother-colony, being ultimately set free by the rupture of the latter.

The asexual method of colony formation goes on for several generations, after which colonies are formed which reproduce by the more complicated sexual method. Such a colony shows some fifty large non-flagellate cells, which are destined to produce sexual cells or gametes. Some of these cells simply enlarge, contain granules of reserve food material, and projecting into the central cavity of the colony, form the female gametes, called *macrogametes* or ova. Certain others divide repeatedly and form clusters of 128 bi-flagellate, spindle-shaped male gametes, known as *microgametes* or sperms

(E, F). By the breaking up of the cluster, these microgametes pass into the central cavity of the colony. They swim by means of their flagella towards a macrogamete, and bore their way through its thick envelope (G). A single microgamete fuses with the macrogamete, and forms a fertilized ovum or zygote. The latter surrounds itself with a double cyst-wall (H), the outer one being provided with spiny projections. In this encysted condition, the zygote passes through a long period of winter rest. The parent colony dies, and in the spring the zygote gives rise by a repeated process of cell division to a new Volvox colony.

Volvox presents many points of general biological interest. In the first place, it is an assemblage of zooids or cells comparable with other Protozoa, but linked together and forming a colony. These cells are further differentiated into ordinary vegetative or somatic cells and special reproductive cells. It thus approaches the higher animals or Metazoa, in being multicellular, and in special cells being set apart for reproductive purposes. These reproductive cells have concentrated upon one particular function, and the specialization has led to their losing the more generalized powers. Specialization has gone further, and led to sexual differentiation. Two cells have to meet together in sexual union, and it is an advantage to have stored food material for the early stages of growth of the young colony. Stored food material is a hindrance to active movement. So the microgametes or male gametes are minute but actively motile, and the macrogametes or female gametes are packed with food material but stationary.

Volvox offers another interesting problem for solution. Is it an animal or a plant? If it is an animal, owing to its possessing flagella and showing movement, it is a plant, as it feeds like one by virtue of possessing chloro-

phyll. Botanists claim it as a plant, and zoologists are unwilling to give up the study of so interesting a form. It is a highly specialized representative of early forms, from which both animals and plants were evolved.

Class Flagellata.—The class includes a very large number of forms showing a great variety in structure and habitat. The only character common to them all is the presence of one or more flagella. The class is divided into two sub-classes—viz., *Phytomastigina* the members of which, like *Euglena* and *Volvox*, are predominantly holophytic or plant-like in their mode of nutrition, and *Zoomastigina*, which have a holozoic mode of nutrition and are evidently animal in nature.

The majority of flagellates belonging to the sub-class *Phytomastigina* are free-living organisms. A few of them belonging to the genus *Copromonas* occur in stale fæces or as parasites in the intestine of tadpoles.

The sub-class *Zoomastigina* includes many free-living forms, as well as various parasitic or saprophytic flagellates which occur in man and other animals. Some of them ingest solid food at all parts of the surface of the body like Amœba by means of pseudopodia, or through a special mouth-opening, while others absorb proteid matter in solution by a process of osmosis. Some of these latter, known as Trypanosomes, live mostly in the plasma of the blood of various vertebrates, and cause some of the deadliest diseases of man and domesticated animals.

A Trypanosome (Fig. 76) has a long, narrow body, usually pointed at one or both ends, and provided with a flagellum prolonged forward beyond the anterior end. The flagellum can be traced backwards along the body and connected with the latter by a thin, undulating membrane (*u.*). The nuclear apparatus consists of a large central trophonucleus (*n.*), a smaller, more

posteriorly situated kinetonucleus (*k.n.*), and a basal granule (*b.*) from which the flagellum arises. Different species of *Trypanosoma* cause different diseases, the "Sleeping sickness" which is a fatal disease in man in certain parts of Africa being caused by *T. gambiense*, and transmitted by a biting fly popularly known as tsetse-fly.

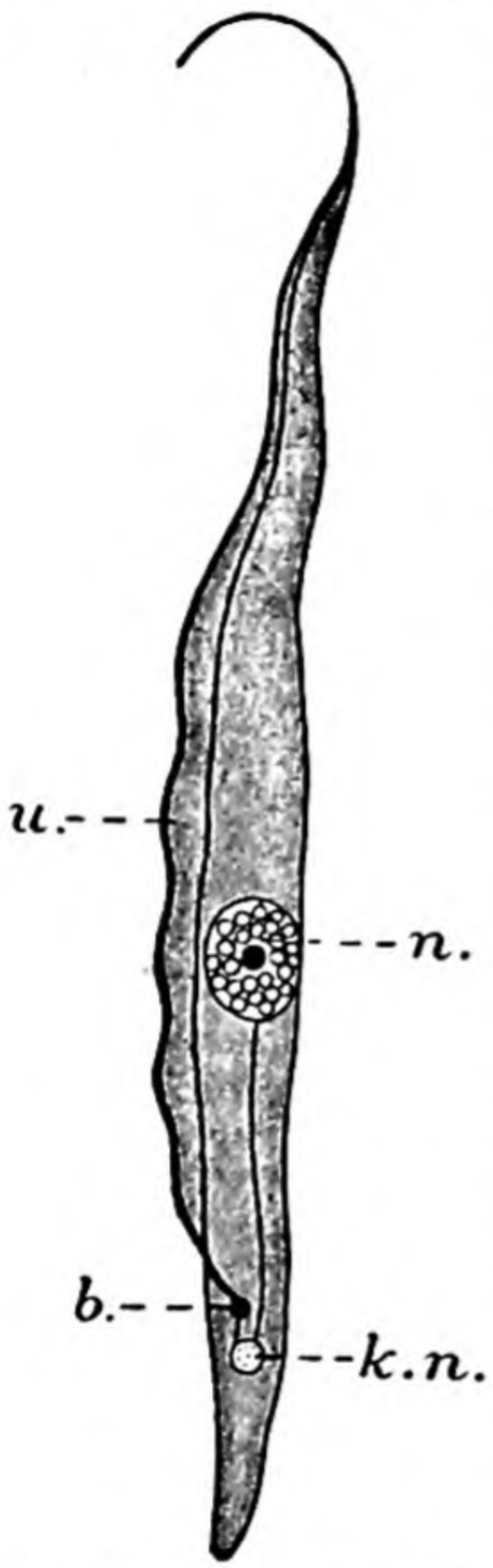


FIG. 76.—A, Trypanosome with a single flagellum. *b.* basal granule; *k.n.* kinetonucleus; *n.* trophonucleus; *u.* undulating membrane. (From Parker and Haswell, after Minchin.)

Differences between Animals and Plants.—It will be useful for the student to institute a comparison between *Amœba* or *Euglena* and any unicellular plant organism, such as *Sphærella* or *Protococcus* or the individual cells of a filamentous alga like *Spirogyra*, that he may have studied in his Botany course. He will remember that in those plant-cells there is no change of form as in Amœba, the protoplasm being surrounded by a definite *cell-wall* consisting of *cellulose*—a carbohydrate allied in composition to starch, sugar, etc., from which substances, however, it can be easily distinguished with the help of certain chemical reagents. Even when Amœba is in the encysted condition, the cyst, as stated above (p. 206), is very probably of some nitrogenous substance. In the matter of nutrition, the differences between Sphærella and Amœba are very marked, and indeed fundamental. As is well known,

these tiny plants, like other green plants, cannot and do not swallow any solid food, but live on water containing various mineral salts and carbon dioxide in solution. They absorb these substances, and in their body build up simple carbohydrates, for which purpose the green chlorophyll contained in their body and the energy supplied by sunlight are essential. The process is known as photosynthesis, and is accompanied by the evolution of oxygen gas. The carbohydrates thus formed unite with the ammonia salts or the nitrates absorbed from the surrounding water, the result being the formation of some comparatively simple nitrogenous compound. Then further combinations take place, substances of greater and greater complexity are produced, sulphur from the absorbed sulphates enters into combination, and proteins are formed. From these, finally, fresh living protoplasm arises.

As in Amœba, the final result of the nutritive process is the manufacture of protoplasm, and this result is attained by the formation of various substances of increasing complexity. But it must be noted that the steps in this process of constructive metabolism are widely different in the two cases. In Amœba we start with living protoplasm—that of the prey—which is killed and broken up into diffusible proteins, these being afterwards re-combined to form new molecules of the living protoplasm of Amœba. So that the food of Amœba is, to begin with, as complex as itself, and is first broken down by digestion into simpler compounds, these being afterwards re-combined into more complex ones. In Sphærella, on the other hand, we start with extremely simple compounds, such as carbon dioxide, water, nitrates, sulphates, &c. Nothing which can be properly called digestion, *i.e.*, a breaking up and dissolving of the food, takes place, but its various con-

stituents are combined into substances of gradually increasing complexity, protoplasm, as before, being the final result.

To express the matter in another way: Amœba can only make protoplasm out of proteins already formed by some other organism: Sphærella can form it out of simple liquid and gaseous inorganic materials.

Speaking generally, it may be said that these two methods of nutrition are respectively characteristic of the two great groups of living things. Animals require solid food containing ready-made proteins, and cannot build up their protoplasm out of simpler compounds. Green plants, *i.e.*, all the ordinary trees, shrubs, weeds, &c., take only liquid and gaseous food, and build up their protoplasm out of carbon dioxide, water, and mineral salts. The first of these methods of nutrition is conveniently distinguished as *holozoic*, or wholly-animal, the second as *holophytic*, or wholly-vegetal.

In Euglena both methods of nutrition are combined. It ingests solid particles of food through the mouth, and also carries on nutrition in a plant-like manner by means of the green chloroplasts contained in the body. Euglena is thus more of an animal than a plant. But when we come to Volvox, the balance of argument is in favour of its being regarded as plant rather than as animal.

In animals as well as plants, destructive metabolism is constantly going on side by side with constructive. The protoplasm becomes oxidized, water, carbon dioxide, and nitrogenous waste matters being formed and finally got rid of. Obviously, then, absorption of oxygen must take place, or, in other words, respiration must be one of the functions of the protoplasm of Sphærella as of that of Amœba. In many green, *i.e.*, chlorophyll-containing, plants, this has been proved to be the case: respiration, *i.e.*, the taking in of oxygen and giving out

of carbon dioxide, is constantly going on, but during daylight is obscured by the converse process—the taking in of carbon dioxide for nutritive purposes, and the giving out of the oxygen liberated by its decomposition. In darkness, when this latter process is in abeyance, the occurrence of respiration is more readily ascertained.

Owing to the constant decomposition, during sunlight, of carbon dioxide, a larger volume of oxygen than of carbon dioxide is evolved; and if an analysis were made of all the ingesta of the organism (carbon dioxide *plus* mineral salts *plus* respiratory oxygen) they would be found to contain less oxygen than the egesta (oxygen from decomposition of carbon dioxide *plus* water, excreted carbon dioxide, and nitrogenous waste); so that the nutritive process in Sphærella is, as a whole, a process of deoxidation. In Amœba, on the other hand, the ingesta (food *plus* respiratory oxygen) contain more oxygen than the egesta (fæces *plus* carbon dioxide, water, and nitrogenous excreta), the nutritive process being therefore on the whole one of oxidation. This difference is, speaking broadly, characteristic of plants and animals generally; animals, as a rule, take in more free oxygen than they give out, while green plants always give out more than they take in.

Destructive metabolism is, however, manifested not only in the formation of waste-products, but in that of substances simpler than protoplasm which remain an integral part of the organism, viz., cellulose and starch.

The cell-wall in plant-cells is formed of cellulose, while the cyst covering an Amœba is probably formed of some nitrogenous substance derived from the protoplasm.

We see then that destructive metabolism may result in the formation of (*a*) *waste products* and (*b*) *plastic products*, the former being got rid of as of no further

use, while the latter remain an integral part of the organism.

We have seen that typical animal-cells, such as those of the frog (Part I, Chap. VII) are not provided with a cellulose cell-wall and do not contain chlorophyll. It is characteristic, on the other hand, of most plant-cells—which also consist of nucleated protoplasm—that they are surrounded with a cellulose cell-wall, and that, in the case of green plants, they contain chlorophyll. Speaking generally, the nutrition of animals is holozoic, and that of green plants holophytic; and in correspondence with this difference in the character of the food, most animals have an ingestive aperture or mouth for taking in the solid food, and some kind of digestive cavity, either permanent (stomach) or temporary (food-vacuole); they also have, as a rule, some kind of excretory apparatus. Moreover, animals are usually capable of automatic movement, while in most plants the organism, as a whole, exhibits no automatism, but only the slow movements of growth.

In the next two chapters we shall study certain other unicellular organisms which show an advance on Amœba and Euglena in possessing a certain amount of morphological and physiological differentiation. But the structural differentiations, as they are merely parts of one cell, cannot be spoken of as " organs " in the sense in which we have used the word hitherto, as they are not composed of numerous cells. They are, however, organs in the physiological sense, as they perform different functions.

(Fig. 77) closely arranged in a single layer and perpendicular to the surface. These are called *trichocysts*.

When a Paramecium is killed, either by the addition of some poisonous reagent or by simple pressure of the cover-glass, it frequently assumes a remarkable appearance. Long delicate threads suddenly appear, projecting from its surface in all directions and looking very much as if the cilia had suddenly protruded to many times their original length. But these filaments have really nothing to do with the cilia; they are contained under ordinary circumstances in the trichocysts, probably coiled up; and by the contraction of the cortex consequent upon any sudden irritation they are projected in the way indicated. In Fig. 77 a few trichocysts (*d. tr.*) are shown in the exploded condition, *i.e.*, with the threads protruded. Most likely these bodies are weapons of offence like the very similar structures (nematocysts) found in polypes (see Chapter V, Fig. 87).

Reproduction.—Paramecium multiplies by simple fission, the division of the body being always preceded by the elongation and subsequent division of the macro- and micro-nucleus (Fig. 78).

Conjugation (p. 211) also occurs, usually after multiplication by fission has gone on for some time. Two Paramecia come into contact by their ventral surfaces; in each of these conjugating individuals or *gametes* the macronucleus takes no part in the process and degenerates, while the micronucleus undergoes a somewhat complicated series of changes; the essential part of the process being the fusion of two products of the division of the micronuclei, one from each gamete. Each of these then contains a single nuclear body, the *conjugation-nucleus*, formed by the union of nuclear matter derived from two distinct individuals, and therefore comparable to the nucleus of the oosperm in the higher animals

(p. 177). The other products of division of the micronucleus disappear, and new macro- and micro-nuclei arise from the conjugation-nucleus. In this case, however, the two entire gametes do not unite to form a zygote, but separate after the process is complete and begin once more to lead an independent existence, when ordinary transverse fission again takes place. Woodruff kept up during nineteen years a race of *Paramecium aurelia*, starting from a single "wild" individual, and after his observations on eleven thousand generations of the Paramecium in question, came to the conclusion that a single cell can reproduce itself indefinitely, under favourable conditions, without recourse to conjugation. During these investigations it was discovered that during continued binary fissions of the individuals, sometimes an internal reorganization of the nuclear apparatus, called endomixis, takes place. The macronucleus gradually disintegrates and is absorbed, and a new one is formed from the micronuclear apparatus.

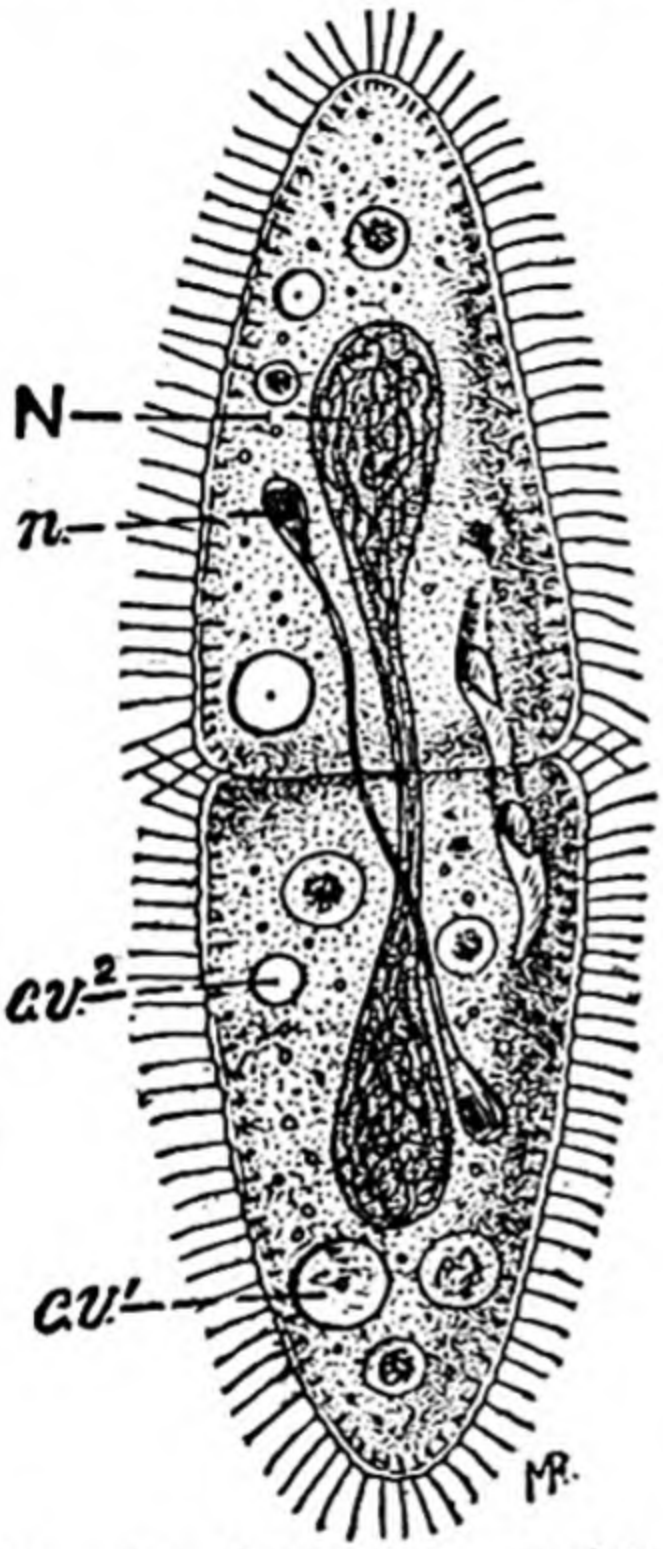


FIG. 78.—*Paramecium caudatum* showing binary fission.
The macronucleus (*N*) divides by amitosis and the micronucleus (*n.*) mitotically; *c.v.*¹, original and *c.v.*², new contractile vacuole in one of the daughter individuals. (From Minchin, after Bütschli and Schewiakoff.)

It will be noticed that, in the present instance (see also p. 211), conjugation is not a process of multiplica-

tion : it has been ascertained that during the time two individuals are conjugating each might have produced a very large number of offspring by continuing to undergo fission at the usual rate. The importance of the process lies in the exchange of nuclear material between the two conjugating individuals, which exercises a stimulating function.

Parasitic Ciliates.—It will be interesting to compare Paramecium with a ciliate infusor which lives in the intestine of *Rana tigrina*, and is known as *Opalina coracoidea*.[1]

Opalina has a flattened body with an oval outline,

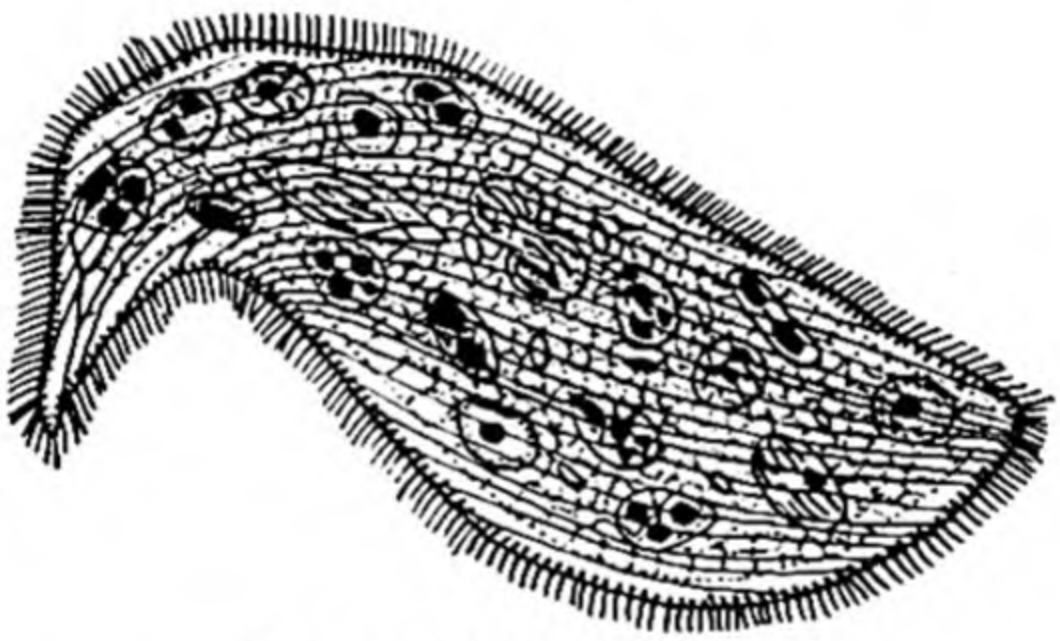


FIG. 79.—*Opalina coracoidea*.
Note the numerous nuclei scattered in the cytoplasm.
(After Bhatia and Gulati from *Fauna of British India*.

and full-sized specimens may be as much as 1 mm. in length. The protoplasm is divided into cortex and medulla, and is covered with a cuticle; the cilia are equal-sized and uniformly arranged in longitudinal rows over the whole surface.

On a first examination no nucleus is apparent, but after staining, a large number of globular nuclei can be

[1] Certain other parasitic ciliates, *e.g.*, *Nyctotherus* and *Balantidium*, are also commonly found in the rectum of *Rana tigrina*.

seen; these nuclei multiply within the body of the infusor.

There is no contractile vacuole, and no trace of either mouth or gullet, so that the ingestion of solid food is impossible. The creature lives, as already stated, in the intestine of the frog: it is therefore an *internal parasite*, or *endoparasite*, having the frog as its *host*. The intestine contains the partially-digested food of the frog, and it is by the absorption of this that the Opalina is nourished. Having no mouth it feeds solely by imbibition: it simply absorbs food ready digested by its host, upon which it is dependent for a constant supply of soluble and diffusible nutriment.

VORTICELLA

Vorticella.—The next organism we have to consider is a ciliate infusor, even commoner than Paramecium. It is hardly possible to examine the water of a pond with any care without finding in it, sometimes attached to weeds, sometimes to the legs of water-fleas, sometimes to the sticks and stones at the bottom, numbers of exquisitely beautiful little creatures, each like an inverted bell with a very long handle, or a wine-glass with a very long stem. These are the well-known "bell-animalcules," the commonest among them belonging to various species of the genus *Vorticella*.

Form and Structure.—The first thing that strikes one about Vorticella (Fig. 80, A) is the fact that it is permanently fixed, like a plant, the proximal or near end of the stalk being always firmly fixed to some aquatic object, while to the distal or far end the body proper of the animalcule is attached.

But in spite of its peculiar form it presents certain very obvious points of resemblance to Paramecium. The protoplasm is divided into cortex (C, *cort*) and

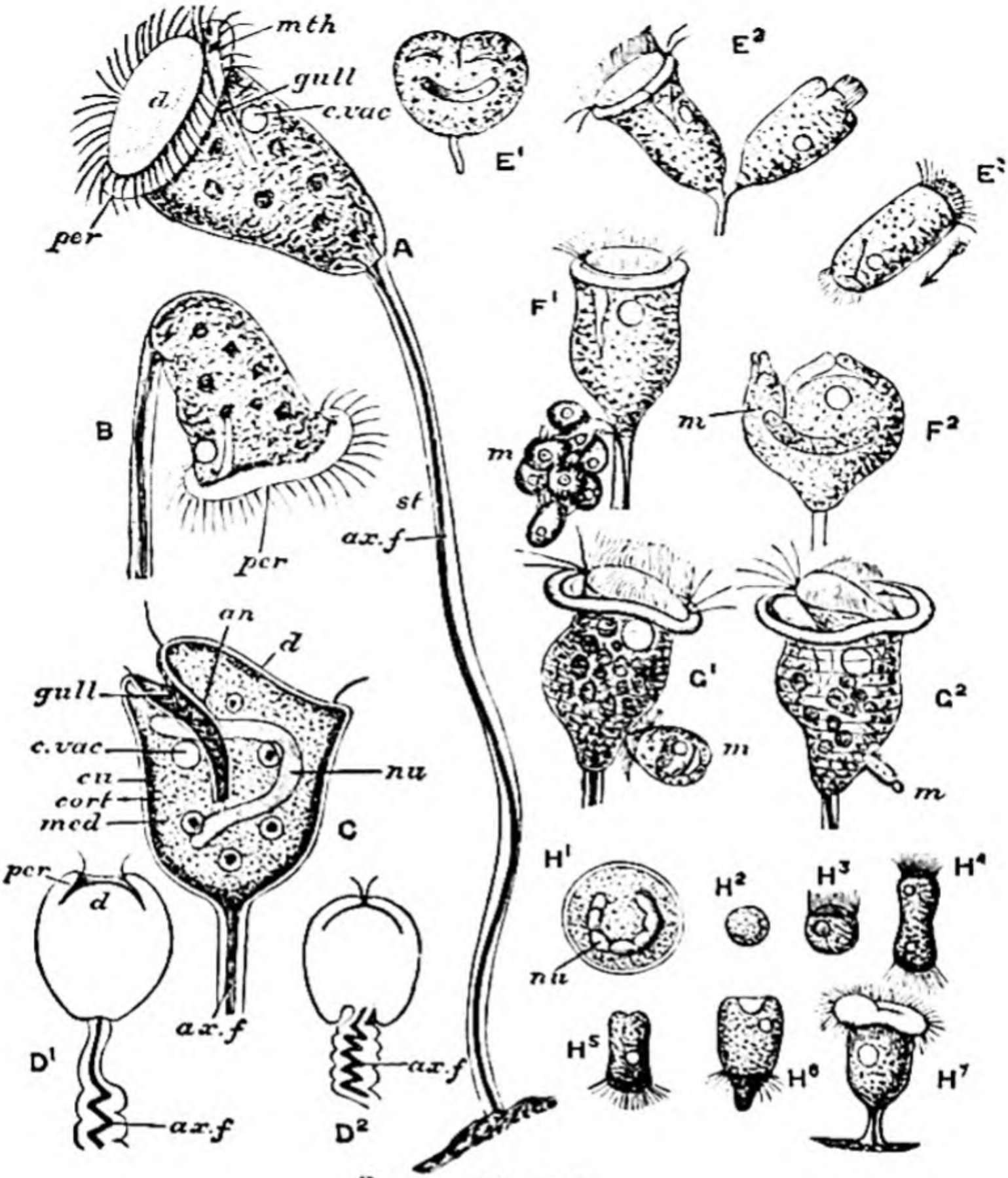


FIG. 80.—*Vorticella.*

A, living specimen fully expanded, showing stalk (*st*) with axial fibre (*ax. f*), peristome (*per*), disc (*d*), cytostome or mouth (*mth*), cytopharynx or gullet (*gull*), and contractile vacuole (*c. vac*). (× 250.)

B, the same, bent on its stalk and with the disc turned away from the observer.

C, optical section of the same, showing cuticle (*cu*), cortex (*cort*), medula (*med*), macronucleus (*nu*), gullet (*gull*), several food vacuoles and anal spot (*an*), as well as the other structures shown in A.

D^1, a half-retracted, and D^2 a fully retracted specimen, showing the coiling of the stalk and overlapping of the disc by the peristome.

E^1, commencement of binary fission; E^2, completion of the process; E^3, the product of division swimming freely in the direction indicated by the arrow.

F^1, a specimen dividing into a macrozooid and several microzooids (*m*); F^2, division into one macro- and one micro-zooid.

G^1, G^2, two stages in conjugation, showing the gradual absorption of the micro-gamete (*m*) into the macrogamete.

H^1, multiple fission of encysted form, the nucleus dividing into numerous masses; H^2, spore formed by multiple fission; H^3–H^6, development of the spore—H^7 is undergoing binary fission. (From Parker's *Biology*: E—H after Savile-Kent.)

medulla (*med*), and is invested with a delicate cuticle (*cu*). There is a single contractile vacuole (*c. vac*) the movements of which are very readily made out owing to the ease with which the attached organism is kept under observation. There is a macronucleus (*nu*) remarkable for its elongated band-like form, and having in its neighbourhood a minute micronucleus. Cilia are also present, but the way in which they are disposed is very peculiar and characteristic. To understand it we must study the form of the body a little more closely.

The conical body is attached by its apex or proximal end to the stalk: its base or distal end is expanded so as to form a thickened rim, the *peristome* (*per*), within which is a plate-like body elevated on one side called the *disc* (*d*), and looking like the partly raised lid of a chalice. Between the raised side of the disc and the peristome is a depression, the *cytostome* or mouth (*mth*), leading into a conical cytopharynx or gullet (*gull*).

There is reason for thinking that the whole proximal region of Vorticella answers to the dorsal surface of Paramecium, and its distal surface with the peristome and disc to the ventral surface of the free-swimming genus: the mouth is to the left in both.

A single row of cilia is disposed round the inner border of the peristome and continued on the one hand down the gullet, and on the other round the elevated portion of the disc; the whole row of cilia thus takes a spiral direction. The rest of the body is completely bare of cilia.

The movements of the cilia produce a very curious optical illusion: as one watches a fully-expanded specimen it is hardly possible to believe that the peristome and disc are not actually revolving—a state of things which would imply that they were discontinuous from the rest of the body. As a matter of fact the appearance is

due to the successive contraction of all the cilia in the same direction, and is analogous to that produced by a strong wind on a field of corn or long grass. The bending down of successive blades of grass produces a series of waves travelling across the field in the direction of the wind. If instead of a field we had a large circle of grass, and if this were acted upon by a cyclone, the wave would travel round the circle, which would then appear to revolve.

Nutrition.—Naturally the movement of the circlet of cilia produces a small whirlpool in the neighbourhood of the Vorticella, as can be seen by introducing finely-powdered carmine into the water. It is through the agency of this whirlpool that food particles are swept into the mouth, surrounded, as in Paramecium, by a globule of water : the food-vacuoles (C) thus constituted circulate in the medullary protoplasm and the non-nutritive parts are finally egested at an anal spot (*an*) situated near the base of the gullet.

Contractility and Irritability.—The stalk (A, *st*) consists of a very delicate, transparent, outer substance, which is continuous with the cuticle of the body and contains a delicate *axial fibre* (*ax. f*) running along it from end to end in a somewhat spiral direction. This fibre is a prolongation of the cortex of the body (C) : under a very high power it appears granular or delicately striated, the striæ being continued into the cortex of the proximal part of the body.

A striking characteristic of Vorticella is its extreme irritability, *i.e.*, the readiness with which it responds to any external stimulus. The slightest jar of the microscope, the contact of some other organism, or even a current of water produced by some free-swimming form like Paramecium, is felt directly by the bell-animalcule, and is followed by an instantaneous change in the

relative position of its parts. The stalk becomes coiled into a close spiral so as to have a mere fraction of its original length, and the body from being bell-shaped becomes globular, the disc being withdrawn and the peristome closed over it (D^1, D^2).

The coiling of the stalk leads us to the consideration of the particular form of contractility called *muscular*, which is met with in multicellular animals, *e.g.*, the frog (p. 58). It was mentioned above that while the stalk in its fully expanded condition is straight, the axial fibre is not straight, but forms a very open spiral, *i.e.*, it does not lie in the centre of the stalk, but at any transverse section is nearer the surface at one spot than elsewhere, and this point as we ascend the stalk is directed successively to all points of the compass.

Now suppose that the axial fibre undergoes a sudden contraction, that is to say, a decrease in length accompanied by an increase in diameter, since, as we have already seen, there is no decrease in volume in protoplasmic contraction. There will naturally follow a corresponding shortening of the elastic cuticular substance which forms the outer layer of the stalk. If the axial fibre were entirely towards one side of the stalk, the result of the contraction would be a flexure of the stalk towards that side, but, as its direction is spiral, the stalk is bent successively in every direction, that is, is thrown into a close, spiral coil.

The axial fibre is therefore a portion of the protoplasm which possesses the property of contractility in a special degree; in which, moreover, contraction takes place in a definite direction—the direction of the length of the fibre—so that its inevitable result is to shorten the fibre and consequently to bring its two ends nearer together. This is the essential characteristic of a muscular contraction, and the axial fibre in the stalk of Vorticella is

therefore to be looked upon as the first instance of a clearly differentiated *muscle* which has come under our notice amongst unicellular animals.

Reproduction.—There are some interesting features in the reproduction of Vorticella. It multiplies by binary fission, dividing through the long axis of the body (E^1, E^2). Hence it is generally said that fission is longitudinal, not transverse, as in Paramecium. But on the theory (p. 238) that the peristome and disc are ventral and the attached end dorsal, fission is really transverse in this case also.

It will be seen from the figures that the process takes place by a cleft appearing at the distal end (E^1) and gradually deepening until there are produced two complete and full-size individuals upon a single stalk (E^2). This state of things does not last long: one of the two daughter-cells takes on a nearly cylindrical form, keeps its disc and peristome retracted, and acquires a new circlet of cilia near its proximal end (E^3): it then detaches itself from the stalk, which it leaves in the sole possession of its sister-cell, and swims about freely for a time. Sooner or later it settles down, becomes attached by its proximal end, loses its basal circlet of cilia, and develops a stalk, which ultimately attains the normal length.

The object of this arrangement is obvious. If, when a Vorticella divided, the plane of fission extended down the stalk until two ordinary fixed forms were produced side by side, the constant repetition of the process would so increase the numbers of the species in a given spot that the food-supply would inevitably run short. This is prevented by one of the two sister-cells produced by fission leading a free existence long enough to enable it to emigrate and settle in a new locality, where the competition with its fellows will be less keen. The

production of these free-swimming zooids is therefore a *means of dispersal*: contrivances having this object in view are a very general characteristic of fixed organisms.

Conjugation occasionally takes place, and presents certain peculiarities. A Vorticella divides either into two unequal parts (F^2) or into two equal halves, one of which divides again into from two to eight daughter-cells (F^1). There are thus produced from one to eight *microzooids* which resemble the barrel-shaped form (E^3) in all but size, and, like it, become detached and swim freely by means of a basal circlet of cilia. After swimming about for a time, one of these microzooids comes in contact with an ordinary form or *macrozooid*, when it attaches itself to it near the proximal end (G^1), and undergoes gradual absorption (G^2), the macro- and micro-zooids becoming completely and permanently fused to form a *zygote* (p. 177).

Notice that in this case the conjugating bodies or gametes are not of equal size and similar character; but one, which is conveniently distinguished as the *microgamete* (= microzooid), is relatively small and active, while the other or *macrogamete* (= macrozooid, or ordinary individual) is relatively large and passive. As we have seen in the case of the frog (pp. 174 and 176), this differentiation of the gametes is precisely what we get in the higher animals, and, in fact, in almost all organisms with two sexes: the microgamete being the male, the macrogamete the female conjugating body (p. 177).

The result of conjugation is somewhat different in the two cases just studied: in Paramecium no zygote is formed, conjugation being a mere temporary union (p. 234): in Vorticella the zygote is an actively moving and feeding body, indistinguishable from an ordinary individual of the species.

Vorticella sometimes encysts itself (Fig. 80, H^1), and

the nucleus of the encysted cell has been observed to break up into a number of separate masses, each doubtless surrounded by a layer of protoplasm. After a time the cyst bursts, and a number of small bodies or *spores* (H^2) emerge from it, each containing one of the products of division of the nucleus. These acquire a circlet of cilia (H^3), by means of which they swim freely, and they are sometimes found to multiply by simple fission (H^4). Finally, they settle down (H^5) by the end at which the cilia are situated, the attached end begins to elongate into a stalk (H^6), this increases in length, the basal circlet of cilia is lost, and a ciliated peristome and disc are formed at the free end (H^7). In this way the ordinary form is assumed by a process of progressive differentiation or *development* (p. 10); and, moreover, the free-swimming young (H^3), to which the spores formed by division of the encysted protoplasm give rise, differ strikingly in form and habits from the adult. This is expressed by saying that development is in this case accompanied by a *metamorphosis*, this word, literally meaning simply a change, being always used in zoology to express a striking and fundamental difference in form and habit between the young and the adult; as, for instance, between the tadpole and the frog, or between the caterpillar and the butterfly. It is obvious that in the present instance metamorphosis is another means of ensuring dispersal.

In Vorticella, as we have seen, fission results not in the production of equal and similar daughter-cells, but of one stalked and one free-swimming form. It is, however, quite possible to conceive of a Vorticella-like organism in which the parent-cell divides into two equal and similar products, each retaining its connection with the stalk. If this process were repeated again and again, and if, further, the plane of fission were extended down-

wards so as to include the distal end of the stalk, the result would be a branched, tree-like stem with a Vorticella-like body at the end of every branch.

Colonial Forms.—As a matter of fact, this process takes place not in Vorticella itself, but in some nearly allied infusors, such as *Carchesium* and *Epistylis*. Each of these forms consists of a main stem attached by its proximal end and giving off at its distal end several

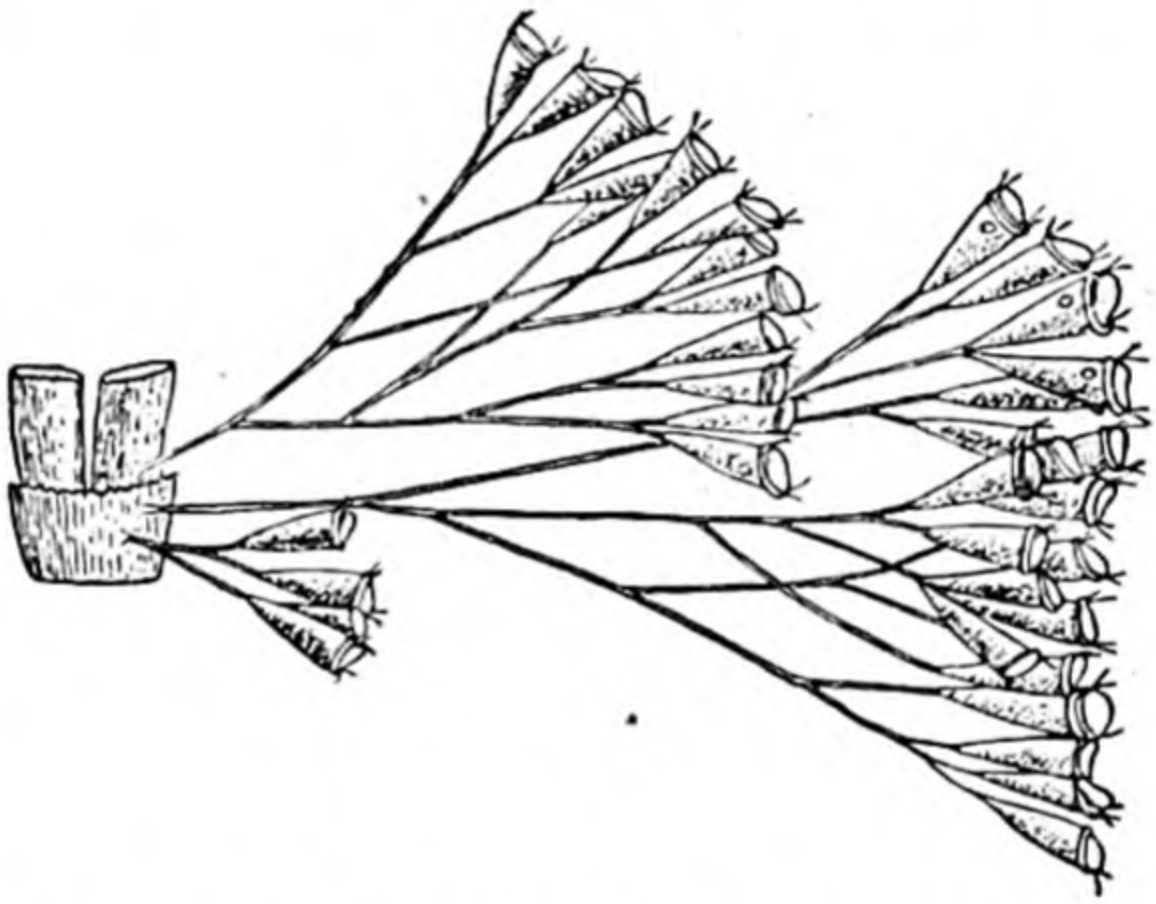


FIG. 81.—*Epistylis anastatica.* (After Kent, from *Fauna of British India.*)

branches, on each of which numerous bell-animalcules with short stalks are borne (Fig. 81).

As in Vorticella, the stem of Carchesium consists of a cuticular sheath with an axial muscle-fibre which, at the distal end of the main stem, branches like the stem itself, a prolongation of it being traceable to each zooid; so that the muscular system is common to the whole colony, and any shock causes a general contraction of all the zooids. The stalk of Epistylis, on the other hand, is non-contractile.

We see, then, that Carchesium and Epistylis differ from all our previous types in being *compound organisms*. The entire "tree" is called a *colony* or *stock*, and each separate bell-animalcule borne thereon is an *individual* or *zooid*, morphologically equivalent to a single Vorticella or Paramecium. The colony is therefore an *individual of a higher grade* than the zooid; and such a multicellular animal as a frog, the cells of which differ markedly in structure and function, is an individual of a higher grade still.

Class Ciliata.—This class includes all Protozoa in which the body has a definite form on account of being covered by a cuticle, and possesses cilia as the organs of locomotion. The arrangement of the cilia differs in different organisms. With the exception of Opalina and its allies, the organisms included in this class show a nuclear differentiation, there being a larger vegetative macronucleus and a smaller reproductive micronucleus. Reproduction takes place by transverse binary fission or by conjugation. Most of them are free-living aquatic forms, but many are parasitic.

Biogenesis and Abiogenesis.—The study of the foregoing living things, and especially of Bacteria, the smallest and probably the simplest of all known organisms naturally leads us to the consideration of one of the most important problems of Biology—the problem of the origin of life.

In all the higher organisms we know that each individual arises in some way or other from a pre-existing individual: no one doubts that every bird now living arose by a process of development from an egg formed in the body of a parent-bird, and that every tree now growing took its origin either from a seed or from a bud produced by a parent-plant. But there have always—until quite recently, at any rate—been upholders

of the view that the lower forms of life, Bacteria, Monads, and the like, may under certain circumstances originate independently of pre-existing organisms: that, for instance, in a flask of some organic infusion boiled so as to kill any living things present in it, fresh forms of life may arise *de novo*—may in fact be created then and there.

We have therefore two theories of the origin of the lower organisms: the theory of *Biogenesis*, according to which each living thing, however simple, arises by a natural process of budding, fission, spore-formation, or what not, from a parent organism; and the theory of *Abiogenesis*, or as it is sometimes called *Spontaneous Generation*, according to which fully-formed living organisms sometimes arise from not-living matter.

In former times the occurrence of abiogenesis was universally believed in. The expression that a piece of meat has "bred maggots"; the opinion that parasites such as the gall-insects of plants or the tape-worms in the intestines of animals originate where they are found; the belief still held in some rural districts that frogs would spring up in large numbers if a dead and dried-up frog was pounded and the powder sprinkled over water, or scorpions would be formed if cow-dung and curd were kept in an earthen pot—all indicate a survival of this belief.

As accurate enquiries into these matters were made, the number of cases in which spontaneous generation was supposed to occur was rapidly diminished. It was not surprising, however, considering the rapidity with which Bacteria and Monads were found to make their appearance in organic substances and infusions, that many men of science imagined them to be produced abiogenetically. The rapid multiplication of these forms means, of course, that a certain amount of fresh living protoplasm has been formed out of the constituents of

dealing with malaria is a great national problem in India, and the student who has acquainted himself with the life-cycle of the malarial parasite should feel interested to know the general principles on which all preventive measures are based. These are :—

(1) To kill the mosquitoes in all stages of their development (Chapter VII).

(2) To save ourselves from being bitten by the mosquitoes.

(3) To destroy the malarial parasites existing in the blood or other parts of the body of persons suffering from the disease.

(4) To kill the parasites that may happen to find their way into the blood of healthy individuals, and thus prevent their subsequent development and multiplication.

Class Sporozoa.—As mentioned before, the class Sporozoa includes organisms which are entirely parasitic —that is, can only live within the body of other animals. There are no free living forms among them. Like parasites belonging to other groups of the animal kingdom, they are degenerate, and have lost their organs of locomotion and food-capture. They absorb food in a liquid form only from the cells or tissues of their host, and neither food-vacuoles nor contractile vacuoles are present. They possess the power of prolific multiplication as a necessary adaptation for the maintenance of the species. Both asexual and sexual methods occur, and, as a rule, regularly recur, thus showing alternation of generations during the course of a more or less complicated life-history. The transference of the parasite from one host to another is effected by means of *spores*, which are thick-walled resistant bodies, containing one or more *sporozoites*, which infect the new host. In the majority of the Sporozoa (Gregarines, Coccidia) the spores are ingested with the food that has been contaminated with

the fæces in which the spores were passed out by an infected host. In other forms, however, as in the Malarial parasites, the asexual part of the life-cycle is passed in the blood of one host, and the sexual part in the body of a widely different host, usually a biting insect, which serves to inoculate or re-introduce the parasites into the blood of a host of the first kind. In such cases, sporozoites are not enclosed within a thick-walled cyst, as they are not subjected to the vicissitudes of the outside world.

Classification of the Protozoa.—Each of the organisms which we have studied in this and the three previous chapters consists of a single cell—or in the case of Volvox or Carchesium and Epistylis of a colony of cells to a large extent independent of one another. They are therefore placed in the lowest primary division of the animal kingdom—the phylum **Protozoa** (p. 197). This phylum is subdivided into a number of *classes*, examples of most of which we have examined.

Class **Sarcodina.** Protozoa devoid of cuticle and possessing pseudopodia. Amœboid form predominant. *Amœba, Entamœba.*

Class **Flagellata.** Protozoa covered with a cuticle and possessing one or more whip-like processes, called flagella. *Euglena, Volvox, Trypanosoma.*

Class **Ciliata.** Protozoa covered with a cuticle and possessing cilia.

Those wholly covered with cilia. *Paramecium, Opalina.*

Those with a single band of cilia. *Vorticella, Carchesium*, etc.

Class **Sporozoa.** Endoparasitic Protozoa devoid of cilia or flagella, in which spore-formation is the usual mode of reproduction. *Plasmodium.*

completely into the theca, and the tentacles become greatly shortened and curved over the manubrium (*P.* 2).

At first (*Bd.* 2) the perisarc is in close contact with the cœnosarc, but during growth a space is formed by the latter retreating from the perisarc for the most part, only processes extending outwards to it at regular intervals. Several annular constrictions are thus caused at the base of each zooid or branch of the perisarc, giving it a ringed appearance.

When the organism dies and decays, the perisarc is left as a semi-transparent, branched structure resembling the living colony in form except that polypes, blastostyles, and medusa-buds are wanting. The perisarc is thus a supporting organ or skeleton, not, like our own bones, formed in the interior of the body (*endoskeleton*), but, like the shell of a prawn or lobster, lying altogether outside the soft parts (*exoskeleton*).

We have already seen that many organisms, such as Sphærella and Amœba, are able to form a cyst or cell-wall, by secreting or separating from the surface of the protoplasm a succession of layers either of cellulose or of a transparent horn-like substance (pp. 206 and 222). The ectoderm-cells of Obelia are in close contact with their neighbours on all sides and with the mesogloea at their inner ends, so the secretion of skeletal substance takes place only at their outer ends. As the process takes place simultaneously in adjacent cells, the result is a continuous layer common to the whole ectoderm instead of a capsule to each individual cell. It is to an exoskeletal structure formed in this way, *i.e.*, by the secretion of successive layers from the free faces of adjacent cells, that the name *cuticle* is in strictness applied in multicellular organisms.

Structure of a Medusa.—The medusæ arise as buds from the special zooids known as the blastostyles.

In the blastostyles both mouth and tentacles are absent, and the hydrotheca of a polype is represented by the gonotheca (*g. th*), which is a cylindrical capsule enclosing the whole structure. It ultimately ruptures at its distal end to allow of the escape of the medusa-buds (*mbd.*). These latter are, in the young condition, mere hollow offshoots of the blastostyle: when fully developed they have the appearance of saucers attached by the middle

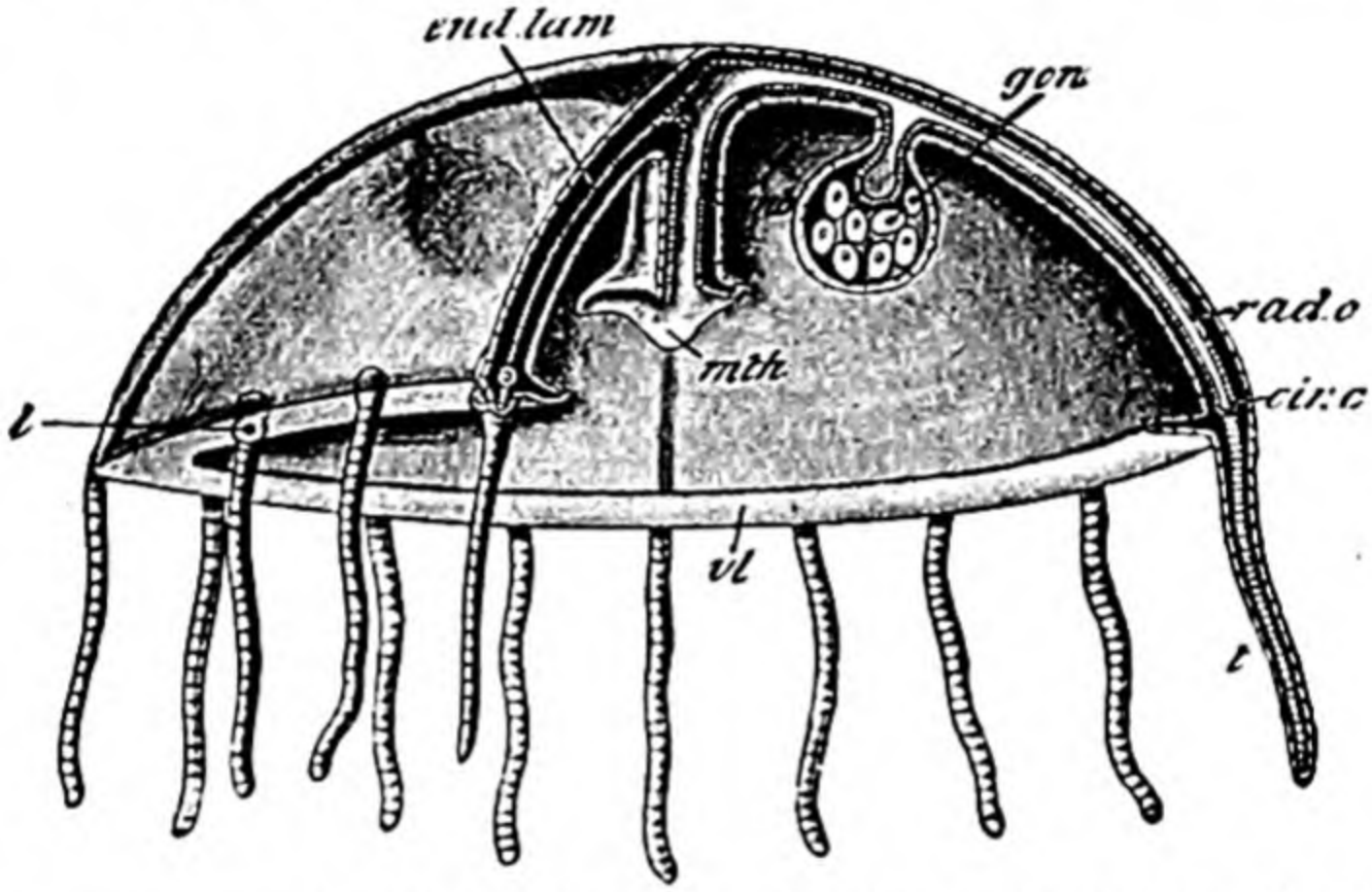


FIG. 89.—Dissection of a *Medusa* (× 25) with rather more than one-quarter of the umbrella and manubrium cut away (diagrammatic). The ectoderm is dotted, the endoderm striated, and the mesogloea black. *cir. c.* circular canal; *end. lam.* endoderm-lamella; *gon.* gonad; *l.* lithocyst; *mnb.* manubrium; *mth.* mouth; *rad. c.* radial canal; *vl.* velum.

of the convex surface to the blastostyle, produced at the edge into sixteen very short tentacles, and having a blunt process, the *manubrium* (*mnb.*), projecting from the centre of the concave surface. They are ultimately set free through the aperture in the gonotheca as little *medusæ* (B–D).

The structure of a medusa must now be described in some detail. The saucer-shaped "bell" or *umbrella* (Figs. 87, B–D, 89, and 90) is formed of a gelatinous

the newly-born medusa, very numerous in the adult. At the bases of eight of the tentacles—two in each quadrant—are minute globular sacs (*l*), each containing a calcareous particle or *lithite*. These are the *marginal sense-organs* or *lithocysts* : in all probability their function is to guide the medusa by enabling it to judge of the direction in which it is swimming. The marginal organs in this case may therefore be looked upon as organs of the sense of direction or of equilibration, and may be spoken of as *statocysts* (compare p. 170). The velum consists of a middle layer of mesogloea with ectoderm on either side : there is no extension of endoderm into it. The tentacles, like those of the polype, are solid, consisting of a core of endoderm covered by ectoderm, which contains numerous stinging-capsules.

Hydroid and Medusa compared.—At first sight there appears to be very little resemblance between a medusa and a polype, but it is really quite easy to derive the one form from the other.

Suppose a simple polype or Hydra-like body with four tentacles (Fig. 90, A, A′) to have the region from which the tentacles spring pulled out so as to form a hollow, transversely extended disc (B). Next, suppose this disc to become bent into the form of a cup with its concavity towards the hypostome, and to undergo a great thickening of its mesogloea. A form would be produced like C, *i.e.*, a medusa-like body with umbrella and manubrium, but with a continuous cavity (C′, *ent. cav*) in the thickness of the umbrella instead of four radial canals. Finally, suppose the inner and outer walls of this cavity to grow towards one another and meet, thus obliterating the cavity, except along four narrow radial areas (D, *rad*) and a circular area near the edge of the umbrella (*cir. c*). This would result in the substitution of the continuous cavity by four radial canals opening on the one hand into

a circular canal and on the other into the enteric cavity (*ent. cav*), and connected with one another by a membrane—the *endoderm-lamella* (D′, *end. lam*)—indicating the former extension of the cavity.

It follows from this that the inner and outer layers of the manubrium are respectively endoderm and ectoderm : that the gelatinous tissue of the umbrella is an immensely thickened mesoglœa : that the layer of cells covering both inner and outer surfaces of the umbrella is ectodermal : and that the layer of cells lining the system of canals, together with the endoderm-lamella, is endodermal.

Thus the polype, the blastostyle and the medusa, are similarly constructed or *homologous* structures (p. 192). The proximal end of the polype corresponds to the apex of the umbrella in the medusa, as both are attached to the common stem by these parts; and the hypostome in the former corresponds to the manubrium in the latter. The Obelia colony is *trimorphic*, bearing zooids of three kinds. In some allied forms this individuation may go still further, the zooids being of very various forms and performing diverse functions : such a colony is said to be *polymorphic*.

Morphological Differentiation.—Sooner or later the medusæ separate from the hydroid colony and begin a free existence in correlation with which they show greater morphological differentiation than the polypes. The rhythmical contraction—*i.e.*, contraction taking place at regular intervals—of the umbrella causes an alternate contraction and expansion of the whole organ, so that water is alternately pumped out of and drawn into it. The obvious resuit of this is that the medusa is propelled through the water by a series of jerks. The movement is due to the contraction of the muscle-processes and muscle-fibres of the sub-umbrella and

17, 18, 19, [redacted], 21 24

velum, some of which differ from the similar structures in the polype in exhibiting a delicate transverse striation.

Nerve cells also show greater differentiation and complexity in their arrangement. At the junction of the velum with the edge of the umbrella there lies, immediately beneath the ectoderm, a layer of peculiar, branched cells, containing large nuclei and produced into long fibre-like processes. These *nerve-cells* (pp. 151 and 268) are so disposed as to form a double ring round the margin of the bell, one ring (Fig. 90, D, *nv*) being immediately above, the other (*nv'*) immediately below the insertion of the velum. An irregular network of similar cells and fibres occurs on the inner or concave face of the bell, between the ectoderm and the layer of muscle-fibres. The whole constitutes the *nervous system* of the medusa; the double nerve-ring is the *central*, the network the *peripheral* nervous system (p. 137).

Some of the processes of the nerve-cells are connected with ordinary ectoderm-cells, which thus as it were connect the nervous system with the external world: others, in some instances at least, are probably directly connected with muscle-fibres.

We thus see that while the manubrium of a medusa has the same simple structure as a polype, the umbrella has undergone a very remarkable differentiation of its tissues. Its ordinary ectoderm-cells, instead of being large and eminently contractile, form little more than a thin cellular skin or *epithelium* (p. 101) over the gelatinous mesoglœa: they have largely given up the function of contractility to the muscle-processes or fibres, and serve merely as a protective and sensitive layer.

Similarly the function of automatism, possessed by the whole body of Hydra, is made over to the group of specially modified ectodermal cells which constitute the central nervous system. If a Hydra is cut into any

number of pieces each of them is able to perform the ordinary movements of expansion and contraction, but if the nerve-ring of a medusa is removed by cutting away the edge of the umbrella, the rhythmical swimming movements stop dead: the umbrella is in fact permanently paralysed.

It is not, however, rendered incapable of movement, for a sharp pinch, *i.e.*, an external stimulus, causes a single contraction, showing that the muscles still retain their irritability. But no movement takes place without such external stimulus, each stimulus giving rise infallibly to one single contraction: the power possessed by the entire animal of independently originating movement, *i.e.*, of supplying its own stimuli, is lost with the central nervous system (compare p. 156).

Another instance of morphological and physiological differentiation is furnished by the marginal sense-organs situated at the base of the tentacles (p. 283).

Reproduction.—The polype and the medusa are respectively nutritive and reproductive in function, the reproductive zooids becoming detached and swimming off to found a new colony elsewhere: the polypes are purely nutritive zooids; the medusæ, although capable of feeding, are specially distinguished as reproductive zooids. Hanging at equal distances from the sub-umbrella, in immediate relation with the radial canals, are four ovoid gonads (Fig. 89, *gon*), each consisting of an outer layer of ectoderm continuous with that of the sub-umbrella, an inner layer of endoderm continuous with that of the radial canal and enclosing a prolongation of the latter, and of an intermediate mass of cells derived from the ectoderm which have become differentiated into ova or sperms. As each medusa bears organs of one sex only (spermaries or ovaries, as the case may be), the individual medusæ are unisexual, and not, like Hydra, hermaphro-

CHAPTER VII

PHYLUM ARTHROPODA

CHARACTERS OF THE PHYLUM ARTHROPODA—THE PRAWN —THE COMMON COCKROACH—CLASSIFICATION

If we examine and compare, even casually, a Prawn, a Scorpion, a Centipede, and a Wasp, we see at once that these resemble each other in certain broad features, and differ from the animals we have studied so far. They all have the body consisting of a number of more or less distinct segments; the body is covered in all by a hard, or at least tough, cuticle; they all possess a system of appendages—feelers, jaws, legs, etc., which are modified for the performance of different functions in the different animals mentioned and in the different parts of the body of the same animal, though in every case they are *jointed* and the different segments of each appendage are covered by a hard or tough integument, like the body itself. These external features, together with certain points in the structure and arrangement of the internal organs, are characteristic of the phylum Arthropoda (Gr. *Arthron*, joint, and *pedis*, a foot). In point of numbers the phylum includes more species than the whole of the rest of the animal kingdom put together, which are grouped together mainly into four large classes, each exemplified by one of the four familiar animals referred to above.

Of these, the Prawn differs from the rest in being an aquatic animal breathing by means of branchiæ or gills.

The others are terrestrial, and take in air directly by a system of air tubes. The Prawn is a representative of the class *Crustacea*, the Scorpion of the class *Arachnida*, the Centipede of the class *Myriapoda*, and the Wasp of the class *Insecta*.

The Prawn

The class **Crustacea** comprises a very large number of Arthropods, the great majority of which are inhabitants either of fresh- or of salt-water. Among the more generally known members of this class may be mentioned the Prawns, Shrimps, Lobsters and Crayfish, Crabs and Hermit-crabs, etc. As an example, the common fresh-water Prawn, *Palæmon*, found in slow-running streams and ponds in most places, may be studied, but where there is any difficulty in obtaining them, specimens from the sea of the genus *Penæus*, which can be obtained from the Government Fisheries Station at Ennur, may be substituted. The following description applies more especially to Palæmon, but will serve the purpose in all essential respects for Penœus as well.

External Features.—It will be noticed at once that the Prawn, like the Earthworm, is a bilaterally symmetrical animal, the right and left halves of the body being exactly alike. The Prawn also resembles the Earthworm in being metamerically segmented, though it differs from the latter in its having a smaller and constant number of segments or metameres, as well as by the fact that certain of these are more or less firmly united with one another. The result of this fusion of segments is that two distinct regions can be recognized in the body—an anterior *cephalothorax* and a posterior *abdomen* (Fig. 108). Instead of the soft integument of the Earthworm or of Nereis, the Prawn has a hard enclosing crust of exoskeleton, formed of thickened and

chitinous cuticle; and instead of the short unjointed parapodia of Nereis, there is a series of variously modified appendages—feelers, jaws, legs, etc.—which, like the body itself, are enclosed in a hard, jointed exoskeleton, their movable segments being termed *podomeres*.

The cephalothorax is unjointed and is covered by a cuirass-like structure, the *carapace*; and the abdomen is divided into distinct segments, movable upon one another in a vertical plane. The cephalothorax is divided into two regions, an anterior—the *head*, and a

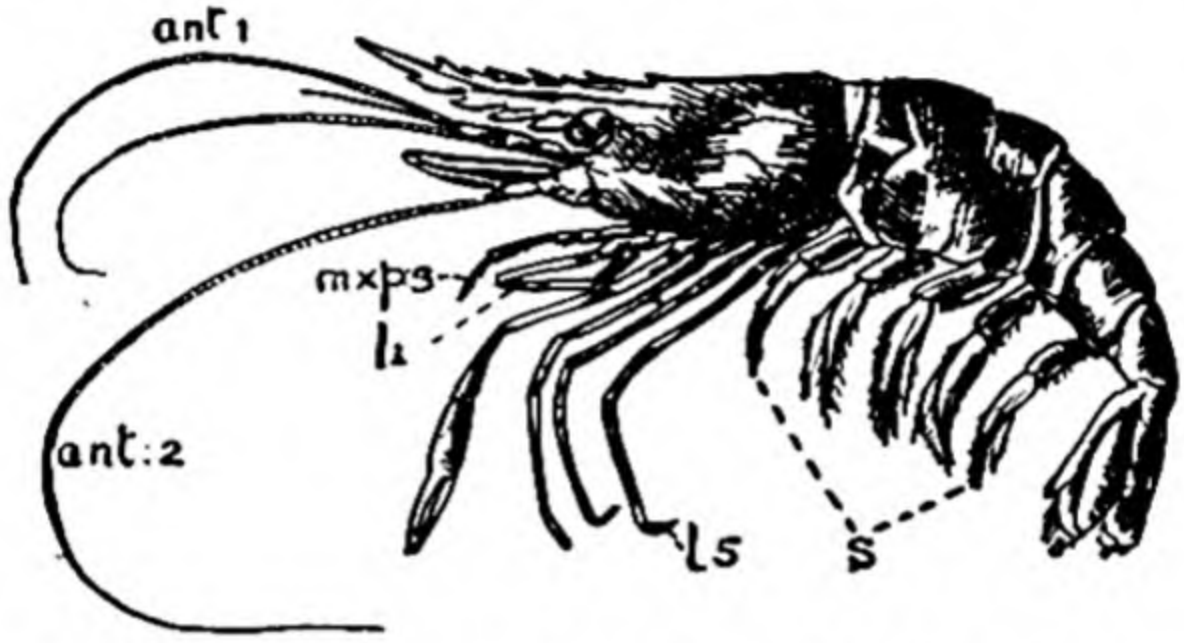


FIG. 108.—The Common Prawn (appendages of one side only shown). *ant.* 1. antennule; *ant.* 2, antenna; *mxp.* 3, third maxilliped; l_1 to l_5, five walking legs; *S.* swimmerets. (After Lulham.)

posterior—the *thorax*, by a transverse depression, the *cervical groove*. The carapace is developed from the dorsal and lateral regions of both head and thorax; it is free at the sides of the thorax, where it forms a flap or *gill-cover* (Fig. 111) on each side separated from the actual body-wall by a narrow space in which the gills are contained. The hinder part of the body is bent downwards from the region of the third abdominal segment.

The limbs spring from the ventral surface. Both trunk and appendages are covered with a sort of shell formed of *chitin* (p. 294), which is hard and elastic.

The *abdomen* is made up of seven segments: the first

six of these are to be considered as metameres in the sense in which the word is used in the case of the Earthworm. The shell surrounding each has a ring-like form, presenting a broad and arching dorsal region or *tergum* (Fig. 109), which is continued downwards into lateral processes, the *pleura* (*p*), a flattened ventral region or sternum, and between the point of attachment of each appendage and the pleuron, the *epimeron* (*Ep*). The seventh division of the abdomen is the

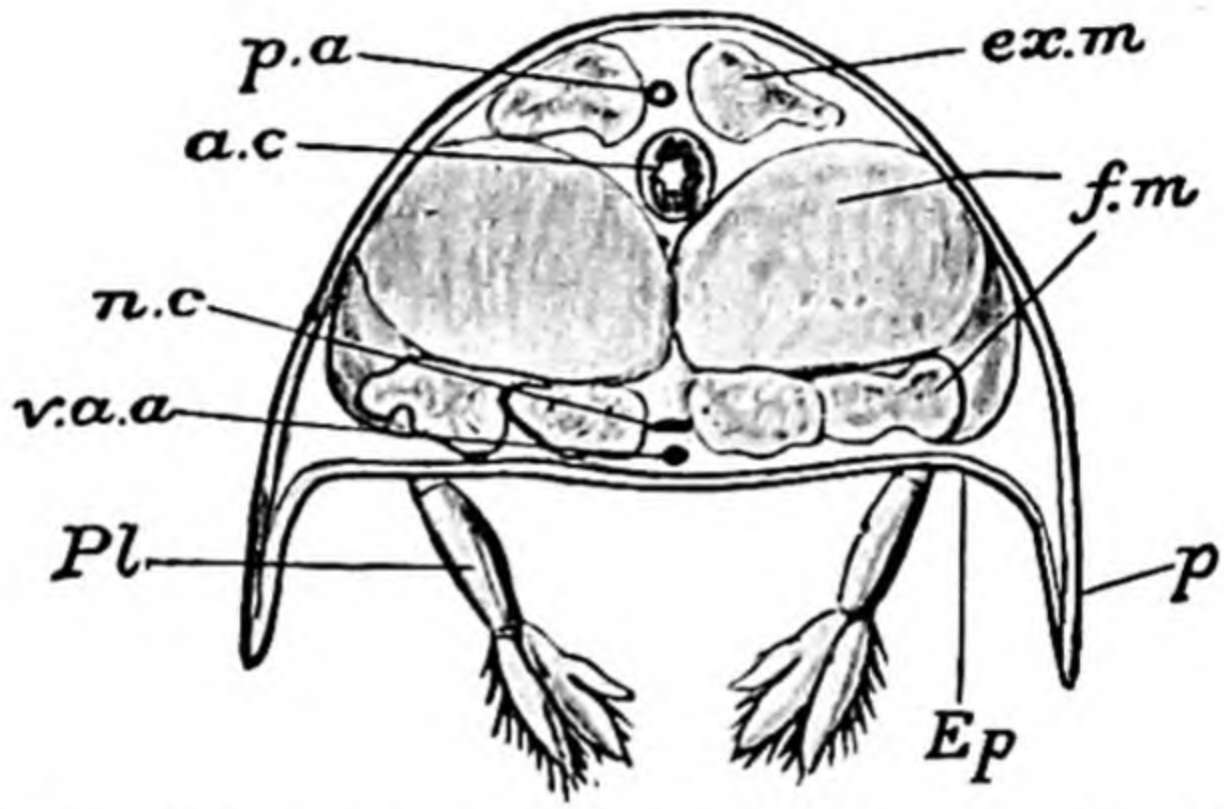


FIG. 109.—Transverse section through abdomen of a Prawn. *a. c.* alimentary canal; *exm.* dorsal or extensor muscle of the abdomen; *Ep.* epimeron; *fm.* ventral or flexor muscles of the abdomen; *n. c.* nerve cord; *p.* pleuron; *p. a.* dorsal abdominal artery; *Pl.* pleopod; *v. a. a.* ventral abdominal artery.

pointed *telson* (Fig. 108). All seven segments are covered by a transparent, flexible, chitinous exoskeleton, and are united to one another by soft *articular membranes*; the first segment is similarly joined to the thorax.

It has been stated that the abdominal segments are movable upon one another in a vertical plane, *i.e.*, the whole abdomen can be *extended* or straightened, and *flexed* or bent under the cephalothorax; the segments are incapable of movement from side to side. This is due to the fact that, while adjacent segments are united an-

nected dorsally and ventrally by flexible articular membranes, they present at each side a *joint*, placed at the junction of the tergum and pleuron, and formed by a little peg-like process of one segment fitting into a depression or socket in the other.

Owing to the presence of the carapace the *thoracic region* is immovable, and shows no distinction into segments either on its dorsal (tergal) or lateral (pleural) aspect. But on the ventral surface the sterna of the thoracic segments are clearly marked off by transverse grooves, and the hindmost of them is slightly movable. Altogether eight thoracic segments can be counted.

The *head* exhibits no segmentation dorsally: the sterna of the five segments composing it, though fused together, can still be counted. The ventral surface of the head is, in fact, bent upwards, so as to face forwards instead of downwards. The cephalic region of the carapace is produced in front into a large median serrated spine, the *rostrum*: immediately below it is a plate from which spring two movably articulated cylindrical bodies, the *eye-stalks*, bearing the eyes at their ends.

Appendages.—Attached to the soft cuticle between the ventral and lateral portions of the exoskeleton are the limbs or appendages, one pair to each segment; these are much modified in different regions of the body to suit the function they have to perform (Fig. 110). You will at once notice the long feelers attached to the head, the five pairs of legs springing from the thorax, and the little fin-like bodies arising from the sterna of the abdomen. It will be convenient to begin with the last-named region.

The first six segments of the abdomen bear each a pair of small appendages, the swimming feet or *pleopods* (Fig. 109, *Pl*). A typical pleopod (Fig. 110, 16) consists

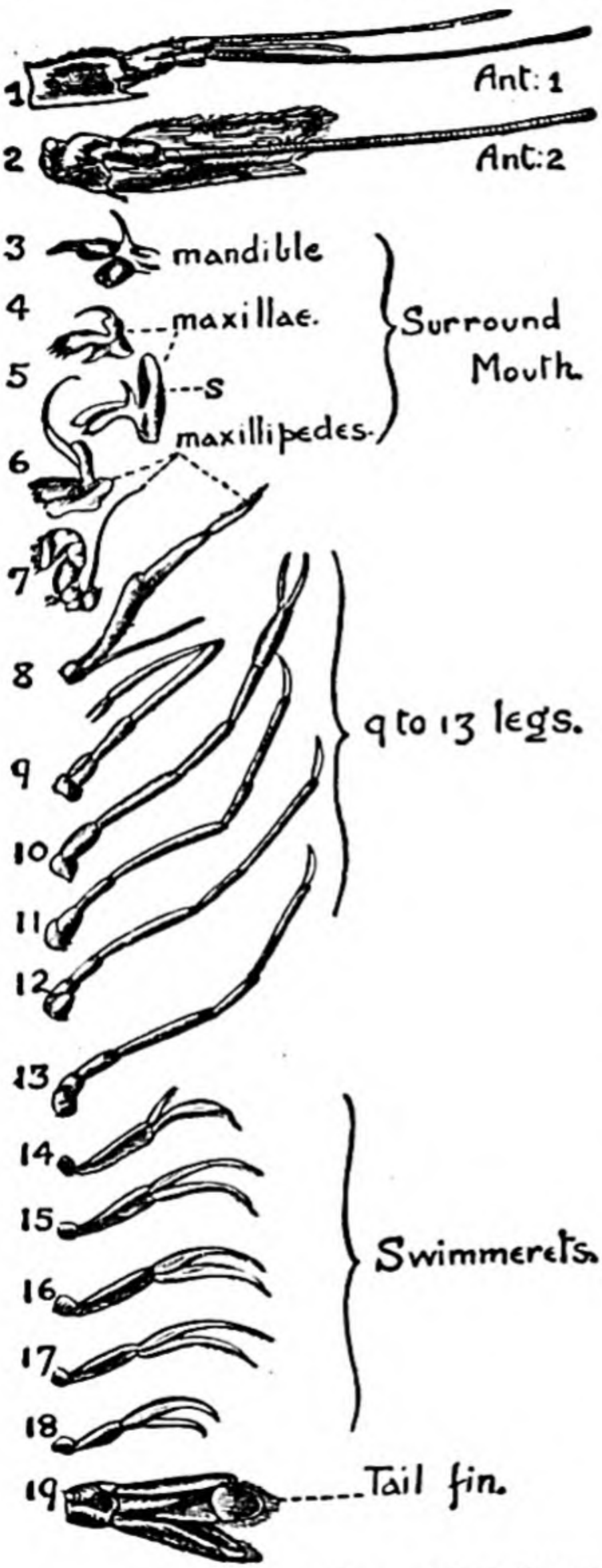


FIG. 110.—The appendages of the Prawn removed from one side of the body and arranged in order.

of an axis or *protopodite* having a very short proximal and a long distal podomere, and bearing at its free end two plates, fringed with setæ, the *endopodite* and *exopodite*. These appendages act as fins, moving backwards and forwards with a regular swing, and probably aiding in the animal's forward movements. The first pleopod in the male is markedly different from that in the female. The endopodite is somewhat larger and the endopodites of the pleopods of the two sides approach towards the median line to form a spout-like structure which serves to transfer the spermatophores to the body of the female. The sixth pair of pleopods (19) are very large, both endopodite and exopodite having the form of broad, flat plates: in the natural

position of the parts they lie one on either side of the telson, forming with it a large five-lobed *tail-fin*: they are therefore conveniently called *uropods* or tail-feet. The telson itself bears no appendages.

The thoracic appendages are very different. The five posterior segments bear long, slender, jointed *legs* (9–13), with which the animal walks: the first two pairs of these terminate in claws or *chelæ*, and hence are called *chelipeds* (Fig. 110, 9–10). The three anterior thoracic segments bear much smaller appendages, more or less leg-like in form, but serving as jaws: they are distinguished as *maxillipedes* or foot-jaws.

The structure of these appendages is best understood by a consideration of the *third maxilliped* (Fig. 110, 8). It shows all the parts of a biramous appendage. The protopodite consists of two segments. From the second of these arises an inner three-jointed endopodite, and an outer unsegmented exopodite. From the outer side of the first segment of the protopodite arises a small lamellar process, the *epipodite*. The first two pairs of maxillipedes are much modified and their basal joints aid in the division of food. In the *second maxilliped* the exopodite is longer than in the third, and the endopodite, which is stouter, consists of five segments and is permanently flexed inwards. In the *first maxilliped* the basal segments are produced inwards as flattened plates, the endopodite is an unsegmented flattened and pointed process, while the expodite is a long, slender and unsegmented branch. There are two leaf-like epipodites attached to the side of the protopodite.

The five *legs* (9–13) differ from the third maxilliped in their greater size, and in having no exopodite: in the fifth or last the epipodite also is absent. The first two of them have undergone a curious modification, by which their ends are converted into pincers or *chelæ*: the fourth segment of the endopodite (sixth of the

entire limb) is produced distally so as to form a claw-like projection, against which the terminal segment bites. The first leg is relatively thin and delicate, and is turned forward on the top of the maxillipedes, lying doubled over just behind them, whilst the second is the largest of all and bears the efficient pincers with which the animal catches its prey.

The head bears a pair of *mandibles* and two pairs of *maxillæ* in relation with the mouth, and in front of that aperture a pair of *antennules* and of *antennæ*. The hindmost appendage of the head is the *second maxilla* (5), a leaf-like appendage, its protopodite being cut up into lobes, while the exopodite is modified into an elongated oval plate known as the scaphognathite (*s*), which sets up a current of water to pass into the gill chamber, and thus serves as an important accessory organ of respiration. The *first maxilla* (4) is a very small organ having neither exopodite nor epipodite. The *mandible* (3) is a large, strongly calcified body, toothed along its inner edge, and bearing on its anterior border a little three-jointed, feeler-like structure, the *palp*, the two distal segments of which represent the endopodite, its proximal segment, together with the mandible proper, the protopodite.

The *antenna* (2) is of great length, being nearly as long as the whole body. It consists of an axis of five podomeres, the fifth or last of which bears a long, flexible, many-jointed structure, or feeler, while from the second segment springs a scale-like body or *squame*. It is fairly obvious that the two proximal segments represent the protopodite, the remaining three, with the feeler, the endopodite, and the squame, the exopodite. On the ventral side of the basal segment of the protopodite is a conical elevation on which the duct of the excretory organ opens.

The *antennule* (1) has an axis of three podomeres ending in three many-jointed feelers; two of them uniting in a common base represent the inner flagellum, which bears the usual relation to the outer flagellum. These are sometimes considered as corresponding to the endopodite and exopodite. But in all the other limbs, as we have seen, the exopodite springs from the second segment of the axis, and the probabilities are that there is no exact correspondence between the parts of the antennule and those of the remaining appendages. The first basal segment is as large as the other two taken together. It is expanded and grooved to lodge the eye on its dorsal side.

The *eye-stalks*, already noticed, arise just above the antennules, and are formed each of a small proximal and a large distal segment. They are sometimes counted as appendages serially homologous with the antennæ and legs, but are more properly to be looked upon as articulated processes of the prostomium.

Movements.—The Prawns creep about on the bed of the stream or on the shoots of the aquatic plants by means of their "walking legs," but, when swimming, these appendages are used little, if at all. A gentle forward swimming motion can be attained by the movement of the swimmerets, but when startled, the Prawn will dart suddenly backwards through the water. This it is enabled to do by violently and suddenly lashing its whole tail forward under its body, which drives the water in front of it, and the reaction causes the body to jerk backwards.

Respiratory System.—The organs of respiration are in the form of gills, contained in a cavity lying below the side flaps of the carapace, which should be cut away on one side, so as to expose them (Fig. 111). There will then be seen seven little white, elongated plates, decreasing

rapidly in size from the largest—attached to the body-wall just above the last walking leg—to the very small anterior one attached to the base of the second maxilliped. These white plates are the gills in which the blood circulates, and in order to keep the blood aërated it is necessary that a constant current of water should pass over them. That this occurs can be demonstrated by putting a little carmine or other easily visible but harmless powder into some pond-water with a living prawn, when

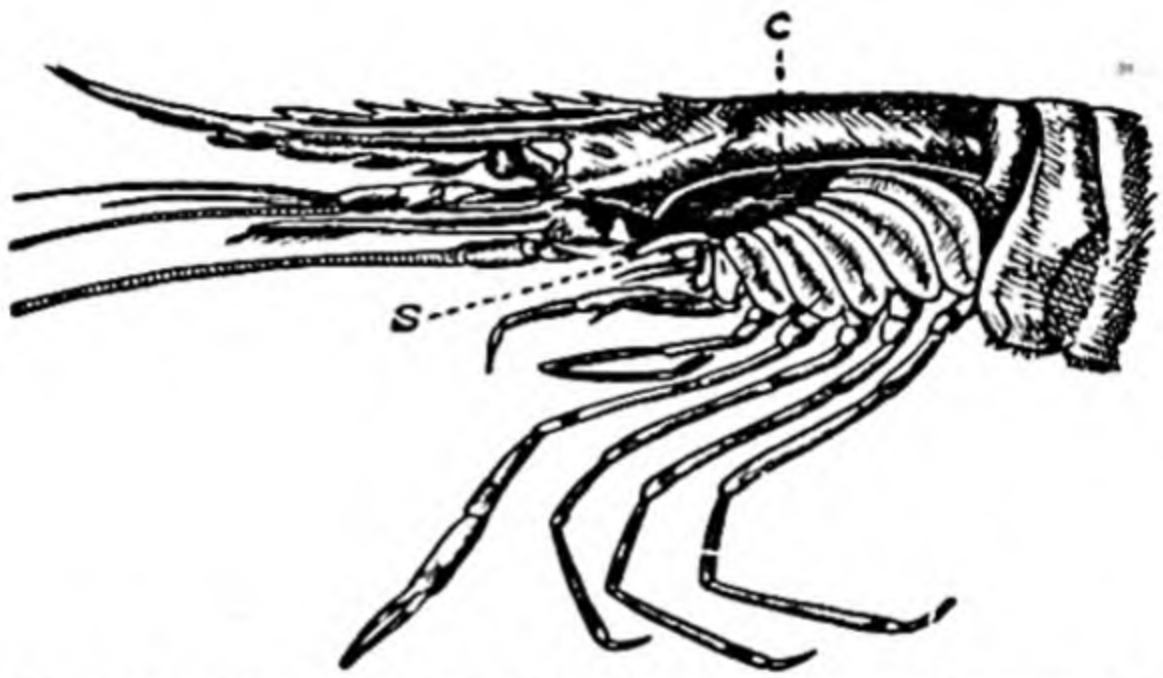


FIG. 111.—View of a Prawn with one side of the carapace cut away, so as to expose the gills.
c, cut edge of the carapace. *s*, scaphognathite, or plate of the second maxilla. (After Lulham.)

the current will carry it in at the back margin of the side of the carapace, and out at the front margin. This current is maintained to some degree by the backward movement of the creature through the water, or when it is at rest by the movement of the little flat horny plate or scaphognathite attached to the second maxilla (Fig. 111, *s*); this plate, by its movement, bales the water out of the gill chamber in front, and so causes fresh water to enter from behind.

Circulatory System.—The circulatory system consists of the **heart** lying enclosed in a sac called the **pericardial sinus,** blood-vessels or arteries issuing from the heart

and a system of returning sinuses and blood-channels. The **heart** (Fig. 112, *h*) is somewhat triangular in form, with its apex directed forwards, and lies dorsally in the posterior part of the thorax, just below the skin. The heart contains an irregular cavity traversed by bundles of muscle-fibres. This cavity communicates with the pericardial sinus through five pairs of openings or *ostia*, four of which are dorsal, and one ventral. The ostia act as valves allowing blood to flow from the pericardial sinus to the heart.

Five arteries arise from the anterior end and one from the posterior part of the ventral surface of the heart. Those arising anteriorly include a pair of large **antennary arteries** (*an. a.*), a pair of **hepatic arteries** (*h. a.*), and a small median **ophthalmic artery** (*oph. a.*). The antennary arteries arise one on either side of the apex of the heart, and after supplying branches to the pericardium, the mandibular muscle, the stomach, etc., run towards the kidneys and supply terminal branches to the kidneys and the antennæ. The hepatic arteries arise from the ventral surface of the heart close to its apex and run downwards into the substance of the hepato-pancreas. The ophthalmic artery runs forwards in the middle line, comes to lie on the dorsal surface of the stomach and passes forwards to the head. The large median artery arising posteriorly, divides at once to form the **supra-intestinal artery** (*s.i. a.*), and the **sternal artery** (*st. a.*). The supra-intestinal artery runs backwards dorsal to the intestine, and supplies the abdominal muscles. The sternal artery runs downwards, perforates the thoracic ganglion, and divides into two branches, which lie ventral to the nerve cord. One of these, known as the **ventral thoracic artery** (*v. th. a.*), runs forwards to the head, and the other, called the **ventral abdominal artery**

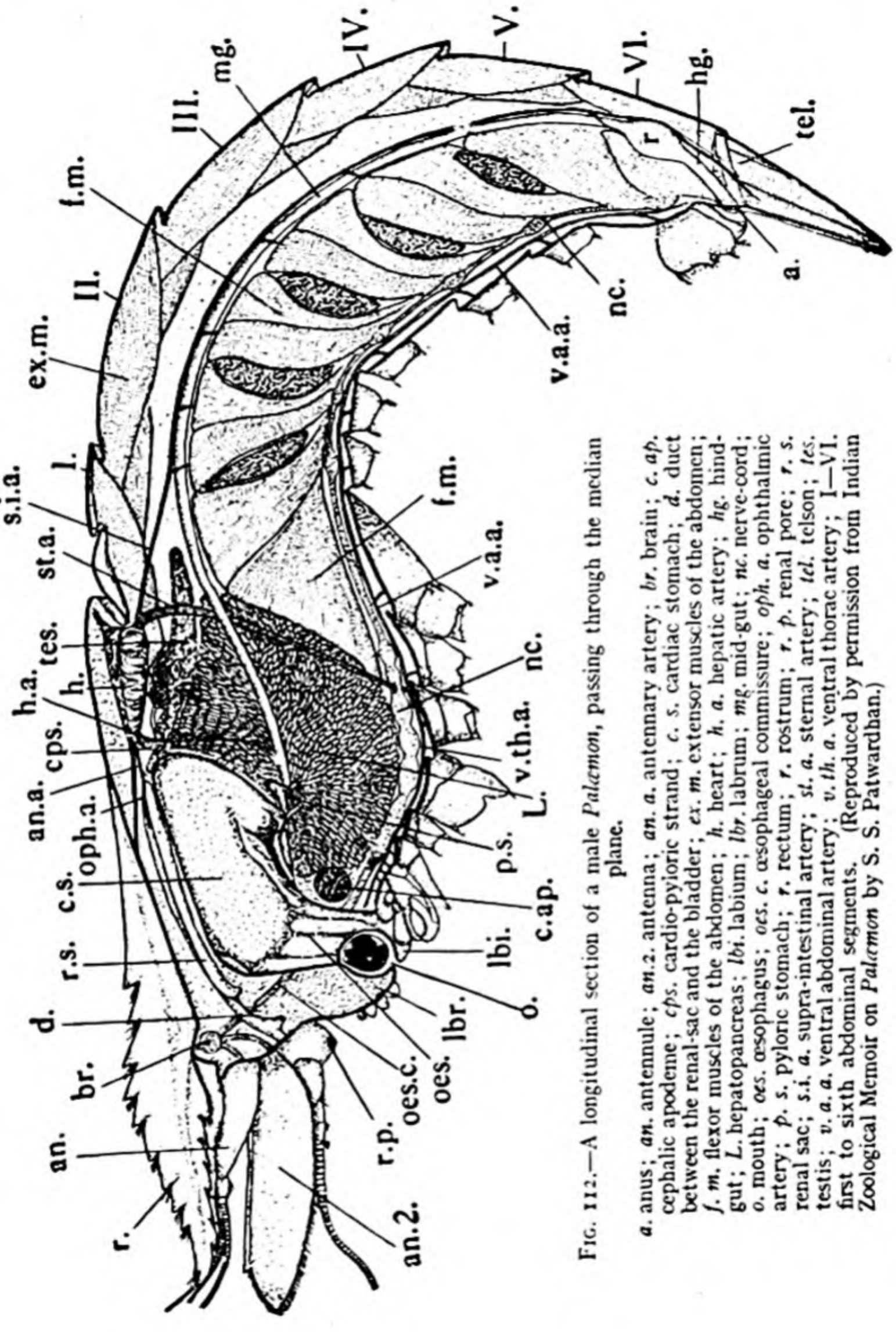


FIG. 112.—A longitudinal section of a male *Palaemon*, passing through the median plane.

a. anus; *an.* antennule; *an.2.* antenna; *an. a.* antennary artery; *br.* brain; *c. ap.* cephalic apodeme; *cps.* cardio-pyloric strand; *c. s.* cardiac stomach; *d.* duct between the renal-sac and the bladder; *ex. m.* extensor muscles of the abdomen; *f. m.* flexor muscles of the abdomen; *h.* heart; *h. a.* hepatic artery; *hg.* hind-gut; *L.* hepatopancreas; *lbi.* labium; *lbr.* labrum; *mg.* mid-gut; *nc.* nerve-cord; *o.* mouth; *oes.* œsophagus; *oes. c.* œsophageal commissure; *oph. a.* ophthalmic artery; *p. s.* pyloric stomach; *r.* rectum; *r.* rostrum; *r. p.* renal pore; *r. s.* renal sac; *s.i. a.* supra-intestinal artery; *st. a.* sternal artery; *tes.* testis; *tel.* telson; *v. a. a.* ventral abdominal artery; *v. th. a.* ventral thorac artery; I—VI. first to sixth abdominal segments. (Reproduced by permission from Indian Zoological Memoir on *Palæmon* by S. S. Patwardhan.)

(*v. a. a.*), goes towards the tail. The arteries branch repeatedly in the various organs, and finally end in minute tubes which open freely into lacunæ or blood-spaces of the hæmocœle. From these spaces the blood is returned to a pair of ventral sinuses running longitudinally along the thorax and the abdomen. From the ventral sinuses the blood is carried into the gills of their respective sides by *afferent branchial channels* and returned by *efferent branchial channels* which open into the pericardial sinus. From the latter the blood passes through the ostia into the heart again.

Digestive System.—Situated between the mandibles is the mouth (Fig. 112, *o.*), with leads into a vertical *œsophagus* (*œs.*), within which the inner tooth of each mandible is placed. These two mandibular teeth rub against each other and serve to grind the food. The œsophagus leads into a large *stomach*, which extends along two-thirds the length of the cephalothorax. The stomach is divided into a very large *cardiac stomach* (*c. s.*), and a smaller and narrower *pyloric stomach* (*p. s.*). Embedded in the floor of the cardiac stomach is a chitinous plate shaped like the head of a spear, and enclosing it are two ridges which serve to direct the food to the opening leading into the pyloric stomach. The pyloric stomach lies ventral to the posterior part of the cardiac stomach and is continued behind as the *mid-gut* or *intestine* (*mg.*), which runs backwards through the abdomen. It is continuous behind with the *hind-gut* (*hg.*), the anterior portion of which is enlarged into a thick-muscular sac (*r.*), and the narrow posterior part opens by the anus (*a.*), situated on the ventral surface of the telson. There is a large digestive gland of a racemose type known as the *hepato-pancreas* or the '*liver*' (*L.*). It is of a reddish-yellow colour and lies ventral to and on either side of the cardiac portion of the stomach,

extending backwards beneath the heart and the reproductive organs. It is traversed by the narrow mid-gut.

The greater length of the alimentary canal consisting of the œsophagus and the stomach (fore-gut) and the posterior part of the alimentary-canal (hind-gut) are lined by a chitinous covering, and develop from the stomadæum and proctodæum respectively. Only the mid-gut has no chitinous lining, and its epithelial lining as well as the hepato-pancreas are of endodermal origin. It may also be noted that there is no grinding apparatus in the stomach of the prawn, as there is in crayfish, lobster, and crab.

Nervous System.—The nervous system is on the same general plan as in the Annelids. There are a pair of *cerebral ganglia* situated anterior to the œsophagus, a pair of *circum-œsophageal connectives*, and a ganglionated *ventral nerve-cord*. Each cerebral ganglion gives off three large nerves, to the eye, and the first and second maxillæ respectively, of the same side. The circum-œsophageal connectives give off small nerves to the œsophagus and the stomach, and are also connected with a small gastric ganglion situated on the anterior wall of the stomach. The ganglia on the ventral nerve-cord are segmental, and the right and left halves of the nerve cord have undergone fusion, so that there is one ganglion in each segment from which nerves are given off to that segment. As the segments of the head and thorax are fused together, some of the cephalic and all the thoracic ganglia are fused to form a single *thoracic ganglionated mass*, which supplies nerves to various appendages of the cephalothorax. Posteriorly a stout cord is continued into the abdomen, and bears a ganglion in each segment.

Sense Organs.—The principal sense organs are the **eyes** and the **statocysts.** The *eyes* are of the compound

type, that is, each eye consists of a large number of separate elongated elements called *ommatidia*. The cuticle covering the distal end of the eye is transparent and serves as the *cornea*. It is divided into a large number of quadrangular facets, each facet being the outer end of an ommatidium. Each ommatidium is a distinct optical system being separated from its neighbours by black pigment. It consists of an outer refractive portion or *vitreous body* and an inner receptive portion or *retinula* formed of sensory cells enclosing a *rhabdom*. The essential plan is the same as in Insecta, and we will consider the structure of the compound eye somewhat more fully in connection with the cockroach.

The *statocysts* are spherical sacs formed by invagination of the dorsal surface of the proximal segment of each antennule, and each communicates with the surrounding water by a small aperture. If one of the statocysts is exposed and examined under the microscope, it will be seen that the lining of the sac is produced into a large number of delicate pointed hairs which receive fibres from the antennulary nerve, and the sac is filled with water which contains minute grains of sand. The statocysts were formerly considered as organs of hearing, but are now believed to be organs for balancing the body.

Excretory Organs.—The excretory function is performed by a pair of renal glands and the associated sacs and ducts. Each renal gland is a somewhat spherical body and lies within the expanded basal segments of the antennæ. It is lined by glandular epithelium and discharges into a thin-walled sac or bladder which opens by a duct on the proximal segment of the antenna. Each gland communicates posteriorly through a narrow duct with an elongated renal sac lying dorsal to the cardiac stomach.

Reproductive Organs.—The sexes are distinct. The abdomen of the female is broader than that of the male. The generative organ in each sex is a tri-lobed greyish body formed by the partial fusion of a pair of gonads, lying in the thorax ventral to the floor of the pericardial sinus, and a pair of genital ducts arise one on either side from the organ. The *vasa deferentia* arising from the *testes* are long and convoluted and open on the proximal segments of the fifth pair of legs. The spermatozoa are peculiar shaped amœboid cells provided with a number of stiff radiating processes. The *oviducts* arising from the *ovaries* are short and pass downwards without convolutions to open on the proximal segments of the third pair of legs. The fertilized eggs are laid and are carried by the female attached to some of her swimmerets until they hatch; they are afterwards protected in a broad pouch made by the bending forward of the abdomen.

The larval Prawns as they hatch out are very unlike the adult; they are little, soft, transparent creatures with only rudiments of the thoracic walking legs, although all the appendages in front of these are well developed; the abdomen also, though fully segmented, has at first no appendages. These larvæ are known as Zooea larvæ. As the immature larva develops, it goes through a series of moults, and when it has acquired its final form and hard exoskeleton, the moult is still continued periodically to allow for the further growth of its body.

The Cockroach

The class **Insecta** comprises the Cockroaches, Grasshoppers, Dragonflies, Houseflies, Mosquitoes, Butterflies, and Bees, with their many allies. The class is a very extensive one, and includes a larger number of species than any other group of the animal kingdom.

approximated as to appear simply like a membrane uniting the valves. At one end, however, the mantle projects between the valves in the form of two short tubes, one (Fig. 153, *ex. sph*) smooth-walled, the other (*in. sph*) beset with delicate processes or tentacles. By diffusing particles of carmine or indigo in the water it can be seen that a current is always passing in at the fringed tube—hence called the *inhalent siphon*, and out at the smooth or *exhalant siphon*. Frequently a semi-transparent, tongue-like body (*ft*) is protruded between the valves at the opposite side from the hinge and at the end farthest from the siphons : this is the *foot*, by means of which the animal is able slowly to plough its way through the sand or mud. When the mussel is irritated the foot and siphons are withdrawn and the valves tightly closed. In a dead animal, on the other hand, the shell always gapes, and it can then be seen that each valve is lined by the corresponding lobe of the mantle, and that the exhalant siphon is formed by the union of the lobes above and below it and is thus an actual short tube; but that the boundary of the inhalant siphon facing the gape of the shell is simply formed by the approximation of the mantle-lobes, so that this tube is a temporary one.

The hinge of the shell is dorsal, the gape ventral, the end bearing the siphons posterior, the end from which the foot is protruded anterior : hence the valves and mantle-lobes are respectively right and left.

In a dead and gaping mussel the general disposition of the parts of the animal is readily seen. The main part of the body lies between the dorsal regions of the valves : it is produced in the middle ventral line into the keel-like foot : and on either side between the foot and the corresponding mantle-lobe are two delicate, striated plates, constituting a *gill* or *ctenidium*, as it is often

called. Thus the whole animal has been compared to a book, the back being represented by the hinge, the covers by the valves, the fly-leaves by the mantle-lobes, the two first and the two last pages by the gills, and the remainder of the leaves by the foot (Fig. 154).

Shell.—When the body of the mussel is removed from the shell the two valves are seen to be united, along a straight *hinge-line*, by a tough, elastic substance, the *hinge-ligament* (Fig. 154, *lg*), passing transversely from valve to valve. It is by the elasticity of this ligament that the shell is opened; it is closed, as we shall see, by muscular action: hence the mere relaxation of the muscles results in opening the shell. In Anodonta the only junction between the two valves is afforded by the ligament, but in Unio each is produced into strong projections and ridges, the *hinge-teeth*, separated by grooves or sockets, and so arranged that the teeth of one valve fit into the sockets of the other.

The valves are marked externally by a series of concentric lines parallel with the free edge or gape, and starting from a swollen knob or elevation, the *umbo*, situated towards the anterior edge of the hinge-line. These lines are *lines of growth*. The shell is thickest at the umbo, which represents the part first formed, and new layers are deposited under and concentrically to this original portion as secretions from the mantle, the shell being, like the armour of the prawn, a *cuticular exoskeleton* (p. 330). As the animal grows each layer projects beyond its predecessor, and in this way successive outcrops are produced, giving rise to the markings in question. In the region of the umbo the shell is usually more or less eroded by the action of the carbonic acid in the water.

The inner surface of the shell also presents characteristic markings. Parallel with the gape, and at a short

distance from it, is a delicate streak caused by the insertion on to the shell of muscular fibres from the edge of the mantle. Beneath the anterior end of the hinge the streak ends in an oval mark, the *anterior adductor impression*, on to which is inserted one of the muscles which close the shell. A similar but larger *posterior adductor impression* lies beneath the posterior end of the hinge (compare Fig. 153, *a. ad*, *p. ad.*) Two smaller markings close behind the anterior adductor impression, dorsal and ventral respectively, mark the insertion of the *anterior retractor* and of the *protractor* muscle: one just anterior to the posterior adductor impression, that of the *posterior retractor*.

The shell consists of three layers, the outer layer, as in the prawn, being uncalcified. Outside is a brown horn-like layer, the *periostracum*, composed of *conchiolin*, a substance allied in composition to chitin. Beneath this is a *prismatic layer* formed of minute prisms of calcium carbonate, separated by thin layers of conchiolin; and, lastly, forming the internal part of the shell is the *nacre*, or "mother-of-pearl," formed of alternate layers of carbonate of lime and conchiolin arranged parallel to the surface. The periostracum and the prismatic layer are secreted from the edge of the mantle only, the pearly layer from the whole of its outer surface. The hinge-ligament is continuous with the periostracum, and is to be looked upon simply as a median uncalcified portion of the shell, which is therefore, in strictness, a single continuous structure.

Body.—By the removal of the shell the body of the animal is seen to be elongated from before backwards, narrow from side to side, produced on either side into a mantle-lobe, and continued ventrally into a keel-like *visceral mass*, which passes below and in front into the foot (Fig. 153, *ft*). Thus each valve of the shell is in

contact with the dorso-lateral region of the body of its own side together with the corresponding mantle-lobe, and it is from the epithelium covering these parts that the shell is formed as a cuticular secretion. The whole space between the two mantle-lobes, containing the gills, visceral mass, and foot, is called the *mantle-cavity*.

A single layer of epithelial cells, the epidermis, covers the whole external surface—*i.e.*, the body proper, both surfaces of the mantle, the gills, and foot; that of the gills and the inner surface of the mantle is ciliated. Beneath the epidermis come connective and muscular tissue, which occupy nearly the whole of the interior of the body not taken up by the viscera, the cœlome being, as we shall see, much reduced. The muscles are all unstriped, and are arranged in distinct bands or sheets, many of them being very large and conspicuous. The largest are the *anterior* and *posterior adductors* (Figs. 153 and 154, *a. ad*, *p. ad*), great cylindrical muscles which pass transversely across the body and are inserted at either end into the valves of the shell, which are approximated by their contraction. Two muscles of much smaller size pass from the foot to the shell, which they serve to draw back: they are the *anterior* and *posterior retractors*. A third extrinsic muscle arises from the shell close to the anterior adductor, and has its fibres spread fan-wise over the visceral mass, acting as a *protractor*. The substance of the foot itself consists of a complex mass of intrinsic muscles, which aid in withdrawing the foot: its protrusion is largely due to vascular turgescence. Lastly, all along the border of the mantle is a row of delicate muscles, which, by their insertion into the shell, give rise to the line already seen.

The *cœlome* is reduced to a single ovoidal chamber, the *pericardium* (Figs. 153 and 154, *pc*), lying in the dorsal region of the body and containing the heart and part of

the intestine: it is lined by cœlomic epithelium, and does not correspond with the pericardial sinus of the Cockroach, which is a blood-space (p. 353). In the remainder of the body the space between the epidermis and the viscera is filled by the muscles and connective-tissue.

Digestive System.—The *mouth* (Fig. 153, *mth*) lies in the middle line just below the anterior adductor. On either side of it are two triangular flaps, the internal and external *labial palps*; the external palps unite with one another in front of the mouth, forming an upper lip; the internal are similarly united behind the mouth, forming a lower lip: both are ciliated externally. The mouth leads by a short *gullet* (*gul*) into a large *stomach* (*st*), which receives the ducts of a pair of irregular, dark brown, *digestive glands* (*d. gl*). The *intestine* (*int*), which is lined by a ciliated epithelium, comes off from the posterior end of the stomach, descends into the visceral mass, where it is coiled upon itself, then ascends parallel to its first portion, turns sharply backwards, and proceeds, as the *rectum* (*rct*), through the pericardium—where it traverses the ventricle of the heart, and above the posterior adductor, finally discharging by the *anus* (*a*) into the exhalant siphon or *cloaca*. The wall of the rectum is produced into a longitudinal ridge or *typhlosole* (Figs. 153 and 154, *ty*), and two similar ridges begin in the stomach and are continued into the first portion of the intestine.

Respiratory System.—The gills consist, as we have seen, of two plate-like bodies, which represent a single ctenidium (see Fig. 154, B), on either side between the visceral mass and the mantle: we have thus *right outer* and *inner gill-laminæ* and *left outer* and *inner gill-laminæ* (Fig. 154). Seen from the surface (Fig. 153), each lamina presents a delicate double striation, being marked by faint lines running parallel with, and by more pro-

nounced lines running at right angles to, the long axis of the organ. Moreover, each lamina is double, being formed of two similar plates, the *inner* and *outer lamellæ*,

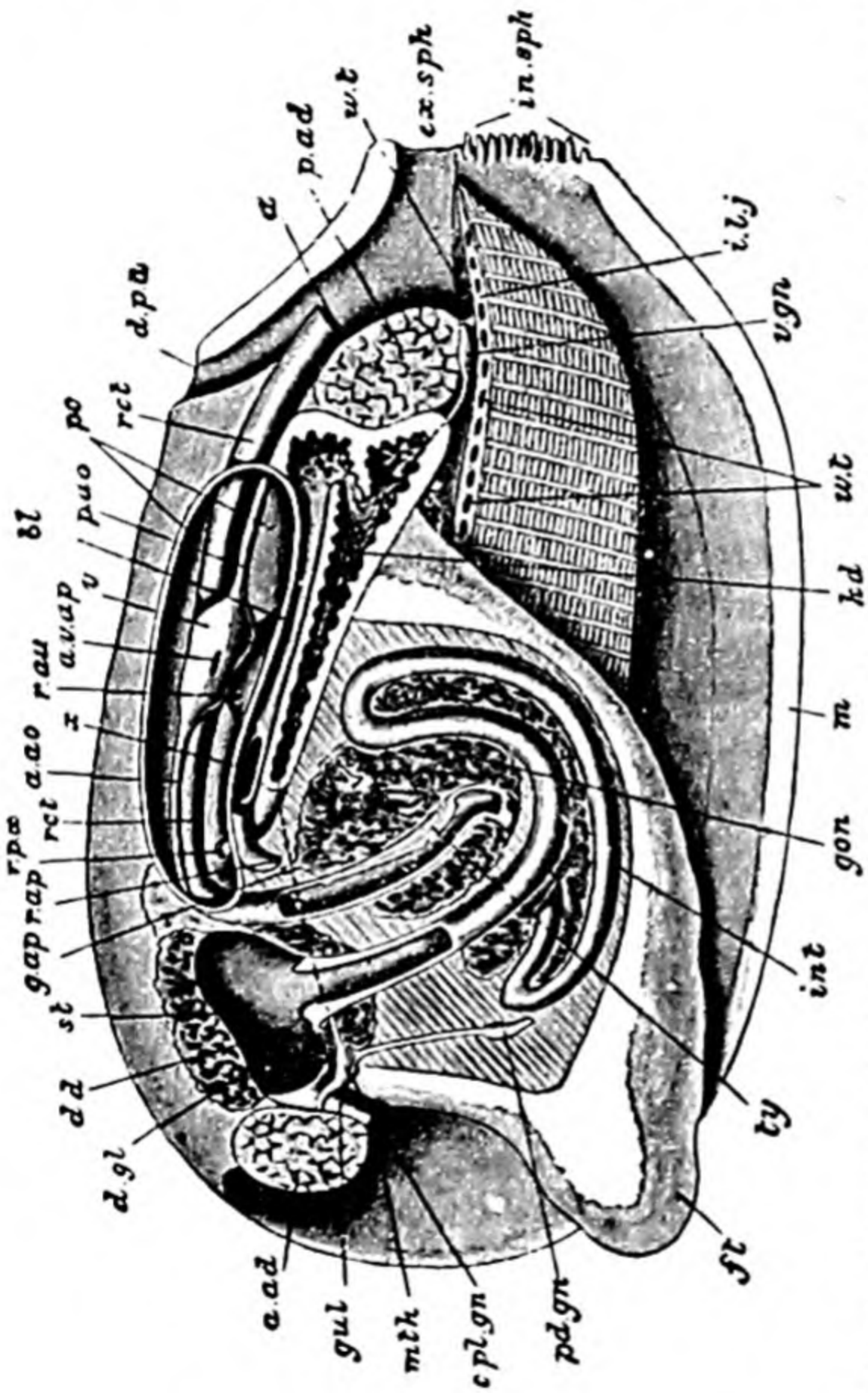


FIG. 153.—Dissection of *Anodonta*, made by removing the mantle-lobe, inner and outer gill laminæ, walls of pericardium, and auricle of the left side; and dissecting away the skin, muscles, &c., of the same side down to the level of the alimentary canal, kidney, nervous system, &c. Part of the alimentary canal is laid open, as also are the kidney (*kd*) and bladder (*bl*). The connection between the cerebro-pleural (*c. pl. gn*) and visceral (*v. gn*) ganglia is indicated by a dotted line. (Nat. size.)

a. anus; *a. ad.* anterior adductor; *a. ao.* anterior aorta; *a. v. ap.* auriculo-ventricular aperture; *bl.* urinary bladder; *c. pl. gn.* cerebro-pleural ganglion; *dd.* duct of digestive gland; *d. gl.* digestive gland; *d. p. a.* dorsal pallial aperture; *ex. sph.* exhalant siphon; *fl.* foot; *g. ap.* genital aperture; *gon.* gonad; *gul.* gullet; *i. l. j.* inter-lamellar junction; *in. sph.* inhalant siphon; *int.* intestine; *kd.* kidney; *m.* mantle; *mth.* mouth; *p. ao.* posterior aorta; *p. ad.* posterior adductor; *pc.* pericardium; *pd. gn.* pedal ganglion; *r. ap.* renal aperture; *r. au.* right auricle; *rct.* rectum; *r. p. a.* reno-pericardial aperture; *sl.* stomach; *ty.* typhlosole; *v.* ventricle; *v. gn.* visceral ganglion; *w. t.* water-tubes; *x.* aperture between left and right bladder. (From Parker and Haswell's *Zoology*.)

united with one another along the anterior, ventral and posterior edges of the lamina, but free dorsally. The lamina has thus the form of a long and extremely shallow

bag, open above (Fig. 154) : its cavity is subdivided by vertical plates of tissue, the *inter-lamellar junctions* (*i.l. j*) which extend between the two lamellæ and divide the intervening space into distinct compartments or *water-tubes* (Fig. 153, *w.t*), closed ventrally, but freely open along the dorsal edge of the gill. The vertical striation of the laminæ is due to the fact that each lamella is made up of a number of close-set *gill-filaments* : the longitudinal striation to the circumstance that these filaments are connected by horizontal bars, the *interfilamentar junctions*. At the thin free or ventral edge of the lamina the filaments of the two lamellæ are continuous with one another, so that each lamina has actually a single set of V-shaped filaments, the outer limbs of which go to form the outer lamella, their inner limbs the inner lamella. Between the filaments, and bounded above and below by the inter-filamentar junctions, are minute apertures which lead from the mantle-cavity through a more or less irregular series of cavities into the interior of the water-tubes. The filaments themselves are supported by chitinous rods, and covered with ciliated epithelium, the large cilia of which produce a current running from the exterior through the apertures into the water-tubes, and finally escaping by the wide dorsal apertures of the latter. The whole organ is traversed by blood-vessels.

The mode of attachment of the gills presents certain features of importance (compare Fig. 154, A, B, C). The outer lamella of the outer lamina is attached along its whole length to the mantle : the inner lamella of the outer and the outer lamella of the inner lamina are attached together to the sides of the visceral mass a little below the origin of the mantle : the inner lamella of the inner lamina is also attached to the visceral mass in front, but is free further back. The gills are longer than the visceral mass, and project behind it, below the

posterior adductor (Figs. 153 and 154, C), as far as the posterior edge of the mantle: in this region the inner lamellæ of the right and left inner laminæ are united with one another, and the dorsal edges of all four laminæ constitute a horizontal partition between the mantle cavity below and the exhalant chamber or cloaca above. Owing to this arrangement it will be seen that the water-tubes all open dorsally into a *supra-branchial chamber* (Fig. 154, *s. br. c*), continuous posteriorly with the cloaca and thus opening on the exterior by the exhalant siphon.

The physiological importance of the gills will now be obvious. By the action of their cilia a current is produced which sets in through the inhalant siphon into the mantle cavity, through the apertures into the water-tubes, thence into the supra-branchial chamber, and out at the exhalant siphon. The in-going current carries with it not only oxygen for the aëration of the blood, but also diatoms, infusoria, and other microscopic organisms, which are swept into the mouth by the cilia covering the labial palps. The out-going current carries with it the various products of excretion and the fæces passed into the cloaca. The action of the gills in producing the food current is more important than their respiratory function, which they share with the mantle.

Excretory System.—The excretory organs are a single pair of curiously modified *nephridia*, situated one on each side of the body just below the pericardium. Each nephridium consists of two parts, a brown, spongy, *glandular portion* or *kidney* (Figs. 153 and 154, *kd*), and a thin-walled, non-glandular part or *bladder* (*bl*). The two parts lie parallel to one another, the bladder being placed dorsally and immediately below the floor of the pericardium: they communicate with one another posteriorly, while in front the kidney opens into the pericardium (*r. p. a*), and the bladder on the exterior

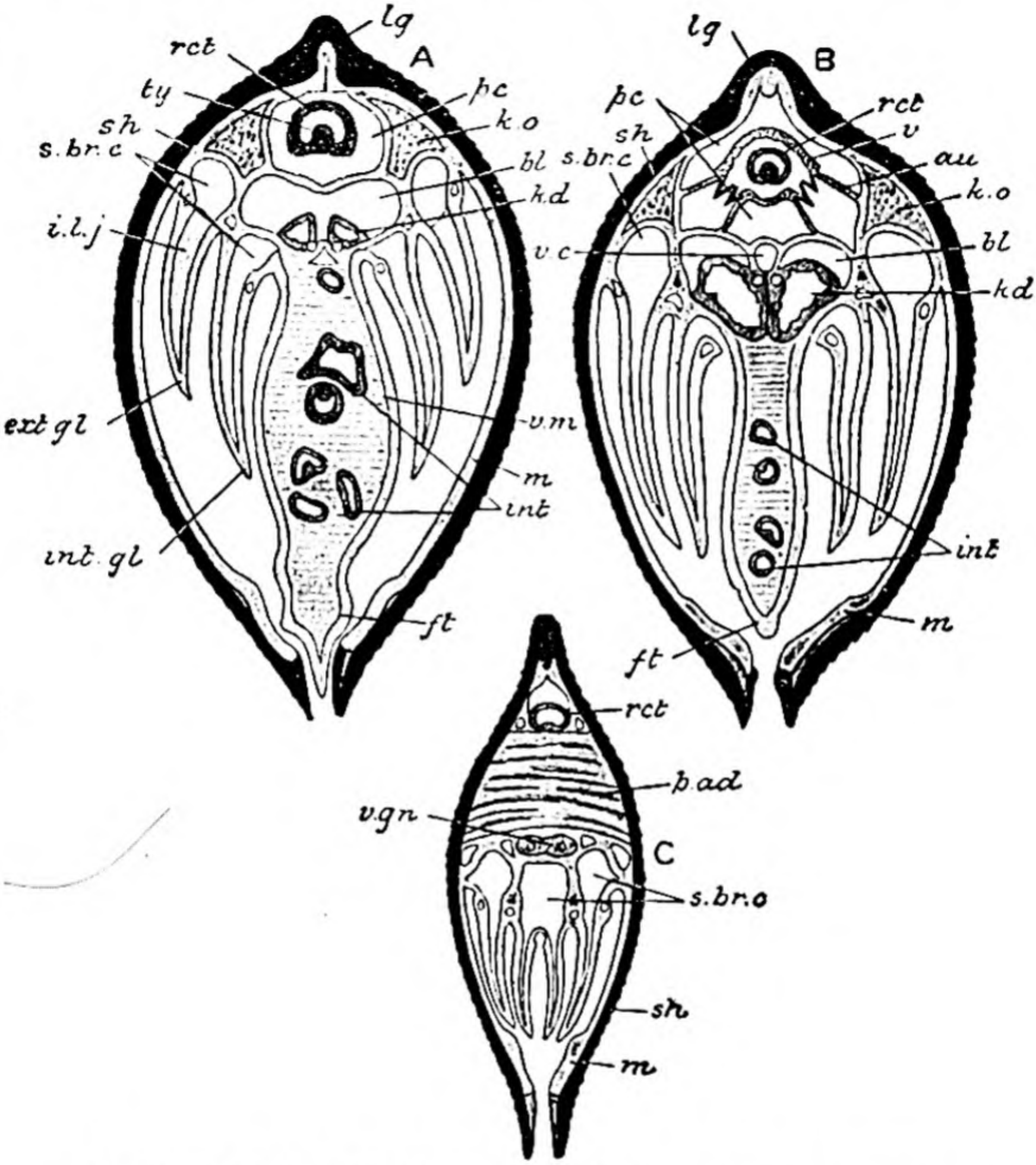


FIG. 154.—*Anodonta*. Three transverse sections (× 1½). A, through the anterior part of the visceral mass. B, through the posterior part of the visceral mass. C, through the posterior adductor muscle.

au. auricle; *bl*. urinary bladder; *ext. gl*. external gill-lamina; *ft*. foot; *i. l. j*. inter-lamellar junction; *int*. intestine; *int. gl*. internal gill-lamina; *kd*. kidney; *k. o*. pericardial gland; *lg*. ligament; *m*. mantle; *p. ad*. posterior adductor; *pc*. pericardium; *rct*. rectum; *s. br. c*. supra-branchial chamber; *sh*. shell; *ty*. typhlosole; *v*. ventricle; *v. c*. vena cava; *v. gn*. visceral ganglion; *v. m*. visceral mass. (From Parker and Haswell's *Zoology*, after Howes, slightly altered.)

by a minute aperture (*r. ap*) situated between the inner gill-lamina and the visceral mass. Thus the whole organ is simply a tube bent upon itself, opening at one end into the cœlome (see p. 301), and at the other on the external surface of the body : it has therefore the normal relations of a nephridium (p. 311). The two bladders communicate anteriorly (Fig. 153, *x*), and their epithelium is ciliated, producing an outward current.

It seems probable that an excretory function is also discharged by a large glandular mass of reddish-brown colour, called the *pericardial gland* or *Keber's organ* (Fig. 154, *k. o*). It lies in the anterior region of the body just in front of the pericardium, into which it discharges.

Circulatory System.—The circulatory system is well developed. The *heart* lies in the pericardium, and consists of a single *ventricle* (Figs. 153 and 154, B, *v*) and of right and left auricles (*au*). The ventricle is a muscular chamber which has the peculiarity of surrounding the rectum (*rct*) : the auricles are thin-walled chambers communicating with the ventricle by valvular apertures opening towards the latter. From each end of the ventricle an artery is given off, the *anterior aorta* (Fig. 153, *a. ao*) extending above, the *posterior aorta* (*p. ao*) below the rectum. From the aortæ the blood passes into arteries (Fig. 155, art^1, art^2) which ramify all over the body, finally forming an extensive network of vessels, many of which are devoid of proper walls and have therefore the nature of sinuses. The returning blood passes into a large longitudinal vein, the *vena cava* (Figs. 154 and 155, *v. c*), placed between the nephridia, whence it is taken to the kidneys themselves (Fig. 155, *nph, v*), thence by *afferent branchial veins* (*af. br. v*) to the gills, and finally returned by *efferent branchial veins* (*e. br. v*) to the auricles. The mantle has a very extensive blood-supply, and probably acts as the chief respiratory

organ (p. 385): its blood (*art*[1]) is returned directly to the auricles without passing through either the kidneys or the gills. The blood is colourless and contains leucocytes. There is no communication between the blood-system and the pericardium.

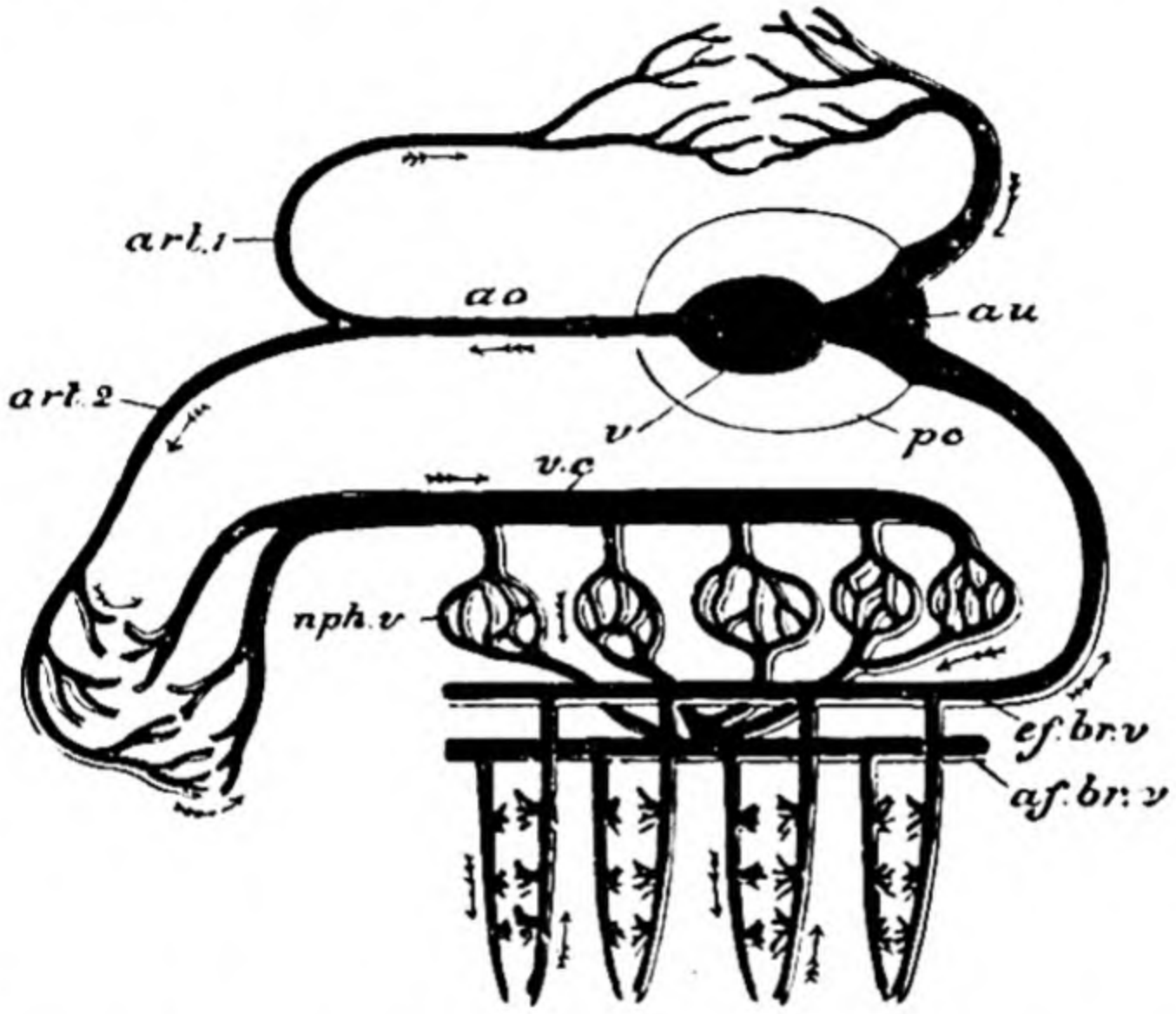


FIG. 155.—Diagram of the circulatory system of *Anodonta*.
The blood received from the auricles (*au*) is pumped by the ventricle (*v*) into the aorta (*ao*) and thence passes to the mantle (*art*[1]) and to the body generally (*art*[2]). The blood which has circulated through the mantle is returned directly to the auricle: that from the body generally is collected into the vena cava (*v. c*), passes by nephridial veins (*nph. v.*) to the kidneys, thence by afferent branchial veins (*af. br. v*) to the gills, and is returned by efferent branchial veins (*ef. br. v*) to the auricles; *pc*. pericardium. (From Parker and Haswell's *Zoology*.)

Nervous System.—The nervous system is formed on a type quite different from anything we have yet met with. On either side of the gullet is a small *cerebro-pleural ganglion* (Fig. 153, *c. pl. gn*), united with its fellow of the opposite side by a nerve-cord, the *cerebral commissure*, passing above the gullet. Each cerebro-pleural ganglion

also gives off a cord, the *cerebro-pedal connective*, which passes downwards and backwards to a *pedal ganglion* (*pd. gn*) situated at the junction of the visceral mass with the foot; the two pedal ganglia are so closely united as to form a single bilobed mass. From each cerebro-pleural ganglion there further proceeds a long *cerebro-visceral connective*, which passes directly backwards through the kidney and ends in a *visceral ganglion* (Figs. 153 and 154 *C*, *v. gn*) situated on the ventral side of the posterior adductor muscle. The visceral, like the pedal ganglia, are fused with one another. The cerebro-pleural ganglia supply the labial palps and the anterior part of the mantle; the pedal, the foot and its muscles; the visceral, the alimentary canal, heart, gills and posterior portion of the mantle. The nerve-cells are confined to the ganglia.

It will be seen that the cerebral commissures and cerebro-pedal connectives, together with the cerebro-pleural and pedal ganglia, form a nerve-ring which surrounds the gullet; the cerebro-pleural ganglia may be looked upon as a supraœsophageal nerve-mass corresponding with the brain of the earthworm and cockroach, and the pedal ganglia as an infraœsophageal mass representing the ventral nerve-cord.

Sensory organs are poorly developed, as might be expected in an animal of such sedentary habits. In connection with each visceral ganglion is a patch of sensory epithelium forming the *osphradium*, the function of which is apparently to test the purity of the water entering by the respiratory current. Close to the pedal ganglia a minute paired *statocyst*, containing a calcareous *lithite* (pp. 170 and 283), is found, the nerve of which is said to spring from the cerebro-pedal connective, being probably derived from the cerebral ganglion. Sensory cells, probably tactile, also occur round the edge of the

mantle, and especially on the tentacles of the inhalant siphon.

Reproductive System.—The sexes are separate. The gonads (Fig. 153, *gon*) are large, paired, racemose (p. 120) bodies, occupying a considerable portion of the visceral mass amongst the coils of the intestine : the spermary is white, the ovary reddish. Each gonad has a short duct which opens (*g. ap*) on the surface of the visceral mass, just in front of the renal aperture.

In the breeding season the eggs, extruded from the genital aperture, pass into the supra-branchial chamber, and so to the cloaca. There, in all probability, they are impregnated by sperms introduced with the respiratory current. The oosperms are then passed into the cavities of the outer gill-laminæ, which they distend enormously. Thus the outer gill-laminæ act as *brood-pouches*, and in them the embryo develops into a peculiar larval form.

Phylum **Mollusca.**—The mussel belongs to the phylum **Mollusca,** which includes, in addition to the bivalved "shell-fish" (such as mussels and oysters), the snails and slugs (which possess a univalved shell), as well as the cuttle-fishes and their allies.

They are unsegmented, triploblastic animals, primitively bilaterally symmetrical, the bilateral symmetry being disturbed in such forms as the snails and the slugs. The bodies of the Molluscs are soft and generally covered by a slimy integument. They are thus fitted for life in the water or in moist places. In most of them the body is supported by a *shell* of calcium carbonate. The shells of snails, cowries, and fresh-water mussels (the latter under the vernacular name of *sipis*) are familiar to every one.

A characteristic organ of the members of this phylum is the ventral muscular *foot* (Fig. 153, *ft.*, Fig. 156 *F.*), which is variously modified; it enables the mussel to

plough its way through the sand, the snail to glide along and the squid to swim through the water and capture its prey. The *mantle* is a fold of the body-wall which secretes the shell. If there are two lobes, a bivalve shell is produced as in the mussel; if one mantle-lobe is present, a univalve shell is formed, as in the snails (Fig. 156). The organs of respiration are the *gills* or *ctenidia*. The Mollusca possess a distinct *cœlome*, which is, however, confined in the adult to the pericardial cavity and the cavities of the reproductive organs.

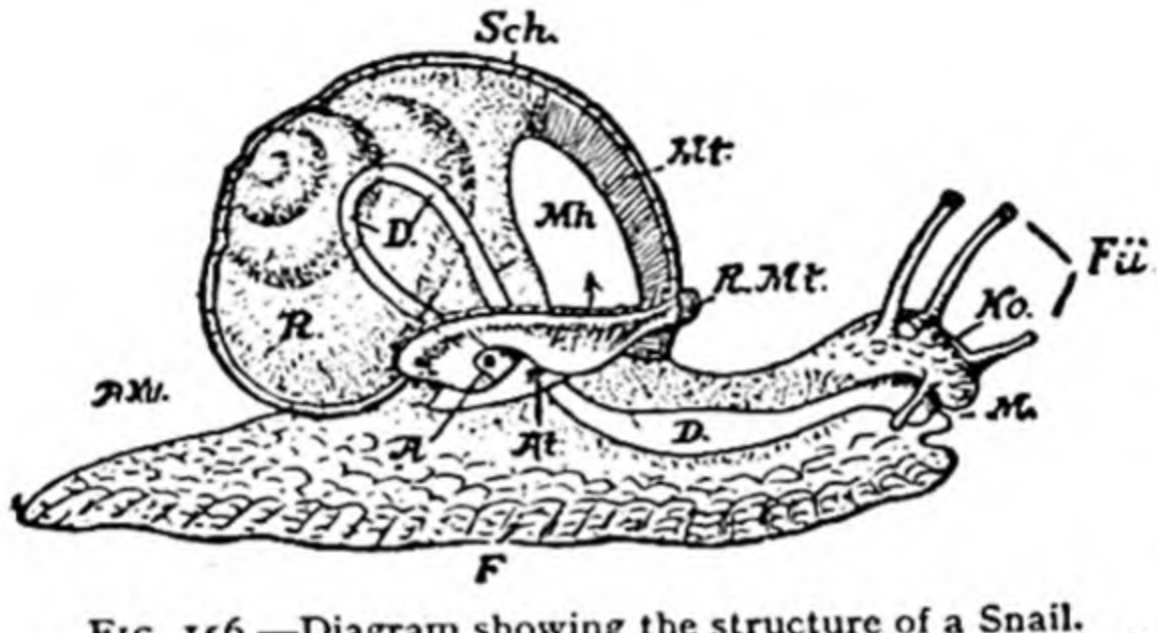


FIG. 156.—Diagram showing the structure of a Snail.
A. anus; *At*. respiratory aperture, the entrance to mantle-cavity indicated by an arrow; *D*, alimentary canal; *F*. foot; *Fü*. tentacles, the larger posterior pair bearing eyes at their tips; *Ko*. head; *M*. mouth; *Mh*. mantle-cavity; *Mt*. mantle; *R. mt*. free edge of mantle; *Sch*. shell. (After Schmeil.)

Classification.—The phylum consists of five classes, of which the principal ones are noted below.

(1) Class **Lamellibranchiata** or **Pelecypoda,** including the bivalved molluscs such as mussels and oysters, the essential structure of which you have learnt from your study of the mussel. Some of them are found in rivers and lakes, but most of them live in the sea. They are bilaterally symmetrical, laterally compressed molluscs, in which the mantle consists of paired right and left lobes, secreting a bivalved calcareous shell. There is no distinct head, and the ventral region of the body is

differentiated into a muscular foot, on each side of which there is a gill or ctenidium.

(2) Class **Gastropoda,** including snails and slugs which are terrestrial, and whelks and periwinkles which are marine. In these molluscs, the mantle is not divided into two lateral folds, and consequently the shell is univalve or composed of a single piece (Fig. 156, *Sch*). The body is flattened from above downwards, and the visceral hump is twisted, thus disturbing the bilateral symmetry. There is a well-developed ventral foot (*F*), usually with a broad, flat surface on which the animal creeps. A head region bears eyes and tentacles. Plume like ctenidia are usually present. In the buccal cavity there is a characteristic organ known as radula bearing numerous minute horny teeth.

(3) Class **Cephalopoda,** including the cuttle-fishes, squids and pearly nautili, are all marine. They have a definitely

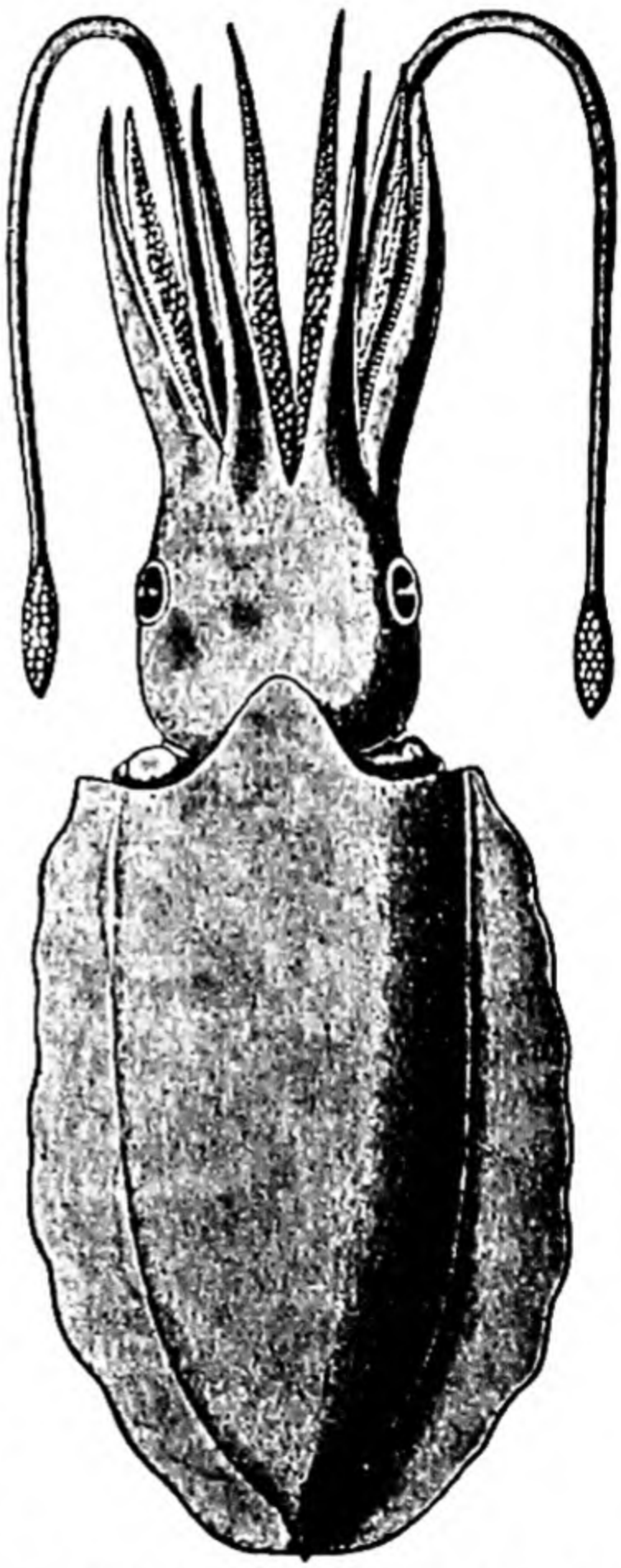


FIG. 157.—A Cuttle-fish, viewed from the antero-dorsal aspect. (From Parker and Haswell's *Zoology*.)

formed head, bearing a pair of highly developed eyes, and surrounded by the anterior portion of the foot modified into arms and tentacles. The body is bilaterally symmetrical. The posterior part of the foot is modified to form a funnel leading out from the large mantle-cavity. A shell is present in most of them, and is usually internal; but in the pearly nautili it is external and divided by septa into a series of chambers, which contain the body of the animal. The visceral mass is symmetrical, and not coiled. The mantle encloses a large cavity in which are situated the ctenidia and the renal, reproductive, and anal apertures. There is a radula in the buccal cavity.

The Mollusca are sharply distinguished from the Annelids and the Arthropods by the absence of segmentation, and by having, as a rule, an exoskeleton in the form of a shell.

CHAPTER IX

BRIEF SURVEY OF THE OTHER PHYLA

WE have so far studied one or more types and surveyed the general organization of the following chief divisions of the animal kingdom :—

Protozoa, Cœlenterata, Annelida, Arthropoda, Mollusca, and Chordata (Sub-phylum Vertebrata).[1]

Besides these, there are a number of other important phyla, and our survey of the animal kingdom will be very incomplete without a brief reference to some of them.

Phylum **Porifera** (Sponges).—In sponges, the body consists of many cells lying in close contact with one another, and usually forming a yellowish, asymmetrical mass of varying size, generally attached to a rock or a seaweed and practically motionless like a plant organism. The surface of a sponge is dotted over with minute pores, and one or more larger openings known as *oscula* (Fig. 158, *O*.) also occur. Sponges live always submerged in water, and if a few grains of carmine or some other pigment are dropped in the water near them, it is seen that the grains are drawn *into* the minute " inhalent " pores, and also that they are *driven away* from the larger " oscula." This current of water is produced by the lashing of the protoplasmic threads or flagella possessed by certain of the cells within the body (see Fig. 159, A, *c*.), and it

[1] The frog has been studied in Part I, as a type of one class of the Vertebrata. Types of other classes of the Chordata will be described in the succeeding chapters.

FIG. 158.—The Purse Sponge (*Grantia compressa*), natural size, attached to a branch of seaweed. O. oscula. (After Lulham.)

carries into the body both the oxygen necessary for respiration and also the decaying organic matter which probably serves as food.

The tough texture of the sponges is due to the spicules, which are of a calcareous or siliceous nature, and are embedded in the mesogloea. They are of very varied shapes in different sponges, and under the microscope are marvels of beauty and symmetry. The spicules may occur alone or combined with a network of horny or silky threads of a substance called *spongin*. In the common Bath Sponges the spongin alone is present, forming the tough supporting skeleton which is sold as a sponge.

These sponges live in deep water, whence they are obtained by divers, or are speared from boats by means of long-handled pronged forks. The living sponges are covered and penetrated throughout by the slimy living tissues, and it is only after these have decayed and the horny skeleton has been washed free from them that the sponge is ready for household use.

Phylum **Platyhelminthes** (Flatworms) consists of small, worm-

FIG. 159.—A. Diagrammatic representation of a longitudinal section through a Sponge of a simple type. *c.* collared cells; *e.* ectoderm; *i.* inhalent pores; *o.* osculum; B. one flagellated collared cell, enlarged. (After Lulham.)

like creatures, with a soft, flattened, bilaterally symmetrical body, which is either unsegmented or consists of a number of similar segments having very little connection with each other.

The flat-worms are more highly organized than the Cœlenterata and are distinctly triploblastic, but, unlike the Annelids, they have no body-cavity or cœlom outside the alimentary canal. The mesoderm forms a kind of connective tissue filling up the space between the alimentary canal and the skin, and several important systems of organs, viz., the muscles, the excretory system, and the reproductive ducts, originate from this layer. There is no circulatory sytem, and the food is carried directly to the tissues through the much-branched digestive tract, which serves, as in the Cœlenterata, as a gastrovascular cavity. There is no anus. The phylum includes the fresh-water planarians, and the parasitic liver-flukes and tape-worms.

FIG. 160.—The Liver-fluke; *excr.* excretory pore; *mo.* mouth; *repr.* reproductive aperture; *sckr.* ventral sucker.

In the liver-flukes the body is provided with suckers (Fig. 160, *sckr.*) by which the parasite clings to the host inside the body of which it lives. The liver-fluke of the sheep (*Fasciola hepatica*) has an extraordinary life-history, passing the adult phase of its life inside the liver of a sheep, and the earlier stages within the body of a water-snail (*Limnæa truncatula*) or of a land-snail (*Helix*). It passes out from the snail on to the grass, and is then swallowed by the sheep when it eats the grass.

The tape-worms (Fig. 162) have a long, ribbon-like, segmented body with no alimentary canal. The seg-

ments are very little dependent on each other; each is capable of reproduction, and separates from the rest when ripe, leaving the body of its host and passing the second phase of its life in another host. *Tænia saginata*

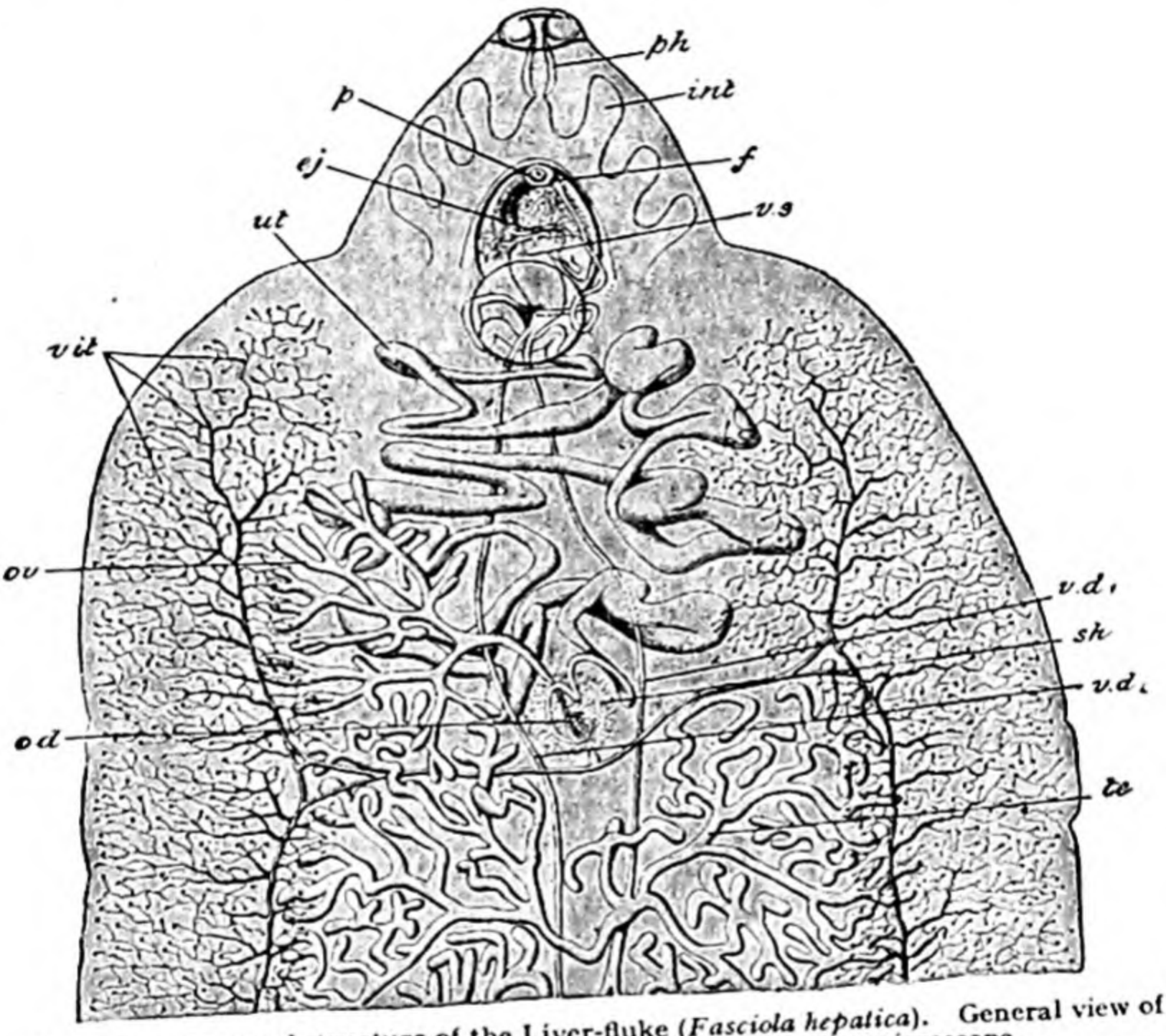


FIG. 161.—Internal structure of the Liver-fluke (*Fasciola hepatica*). General view of the anterior portion of the body, as seen under the microscope.
ej. ejaculatory duct; *f.* female reproductive aperture; *int.* anterior portion of the intestine (the rest is not shown); *od.* commencement of the oviduct; *ov.* ovary; *p.* cirrus; *ph.* pharynx; *sh.* shell-gland; *ts.* testes; *ut.* uterus; *vd.* seminal vesicle. (After Sommer.)

and *T solium* are found as parasites in the human alimentary canal, and pass the second phase of their life in the body respectively of an ox or a pig, and then again infect man if the flesh of these animals is eaten without

in water by means of a secretion from a cement gland in the tail. Although of a microscopic size, the animals show a complicated internal structure. They have a

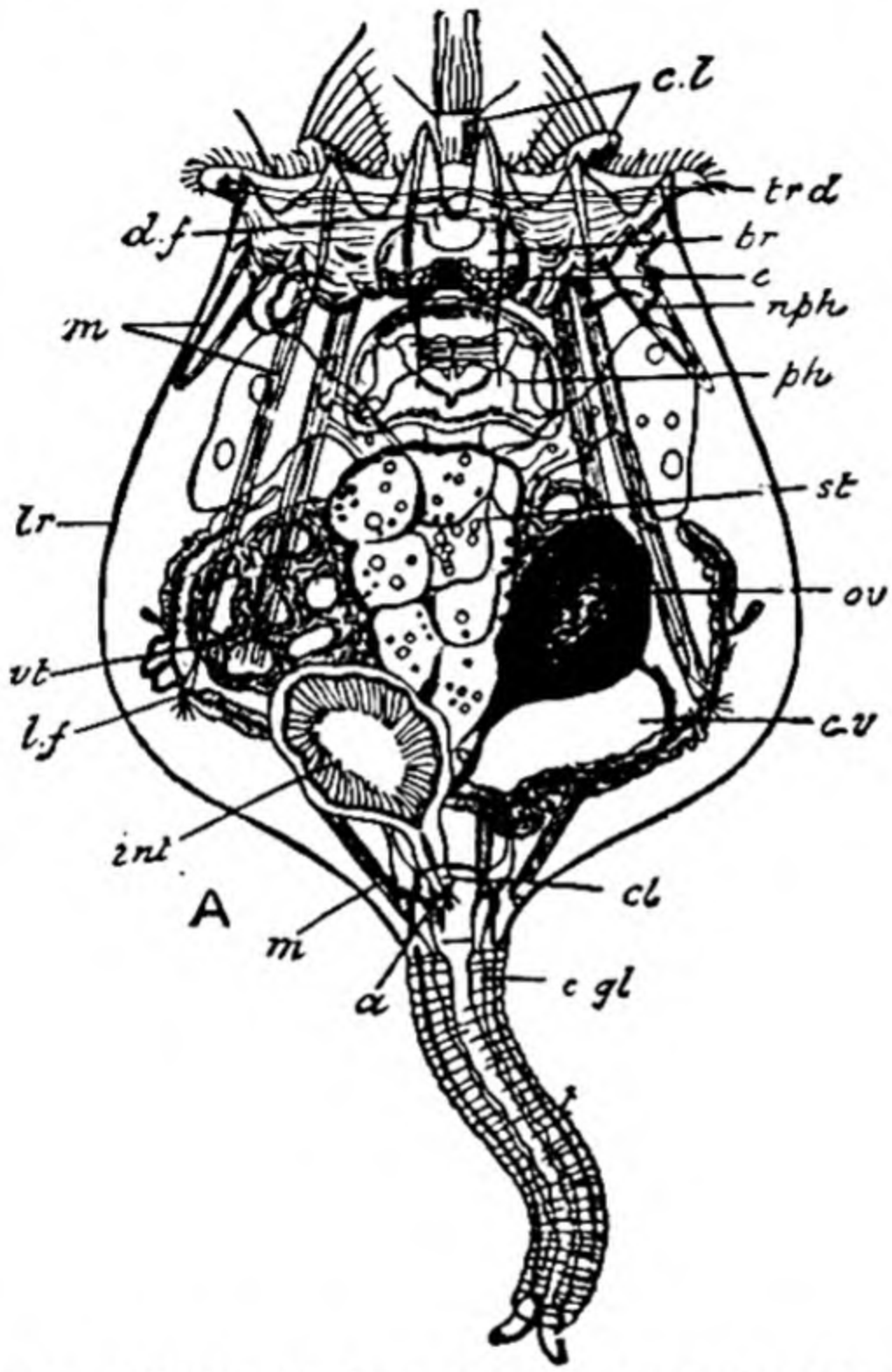


FIG. 164.—A Rotifer (*Brachionus rubens*) as seen under a microscope.
a. anus; *br.* brain; *d. f.* dorsal feeler; *c. gl.* cement gland; *cl.* cloaca; *c. l.* ciliary lobes; *c.v.* contractile vesicle; *e.* eye-spot; *int.* intestine; *lr.* lorica; *l.f.* lateral feeler; *m.* muscular bands; *nph.* nephridial tubes; *ov.* germarium; *ph.* pharynx; *st.* stomach; *t.* tail; *tr. d.* trochal disc; *vt.* vitellarium. (After Hudson and Gosse.)

body-cavity (cœlome) distinct from the alimentary canal, and also excretory, reproductive, and nervous systems, the brain being relatively large, though the sense-organs are very simple. The sexes are separate.

Most of them are inhabitants of fresh water, but some are marine and a few parasitic.

Phylum **Echinodermata.**—The Echinoderms are multicellular animals which, like the Cœlenterates, show a radial type of symmetry, but they differ from the latter in possessing a distinct body-cavity or cœlome lying

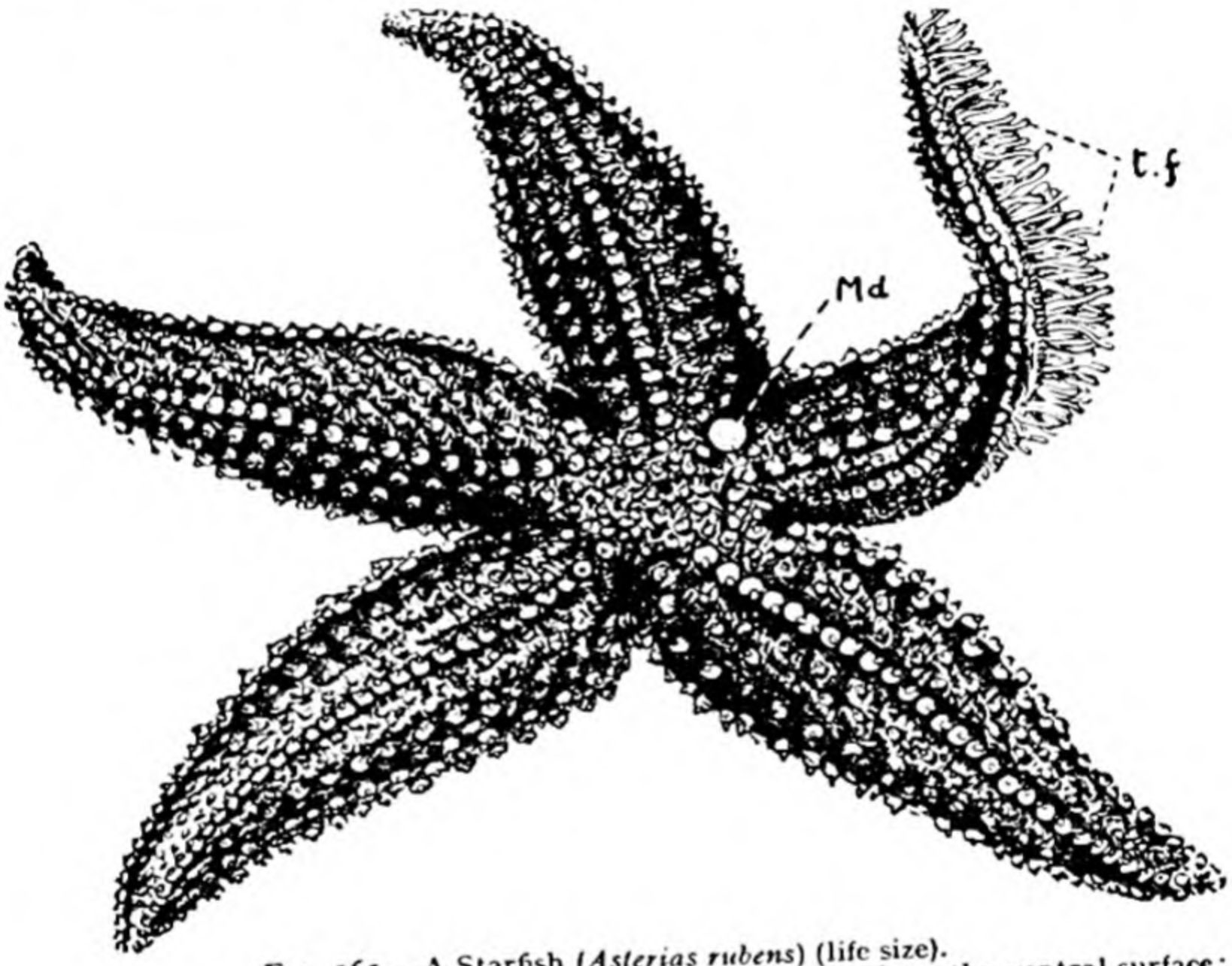


FIG. 165.—A Starfish (*Asterias rubens*) (life size).
Dorsal view: one arm is raised to show the tube-feet, *tf.* on the ventral surface; *md.* madreporite.

outside the alimentary canal and containing various organs in it.

They are usually five-rayed forms, and the skin is hardened by small calcareous plates and spines. A special peculiarity of the members of this phylum is the presence of a peculiar water-vascular system, by means of which water can be taken into the body through an

rise to the main part of the centrum, a separate flat disc of bone (Fig. 189, *ep*) is formed on the anterior and posterior surface of each. These *epiphyses* are characteristic of the vertebræ of all or nearly all Mammals: they unite comparatively late with the centrum proper, and so in disarticulated skeletons of young animals they often come away from the main mass of the centrum and remain attached to the intervertebral discs.

In correspondence with the differentiation of the parts of the body, the vertebral column is divisible into five regions (Fig. 185): the *cervical* in the neck, including seven vertebræ, the first two of which—called respectively the *atlas* and *axis*—are peculiarly modified in order to allow the skull free movement; the *thoracic* in the thorax, twelve or thirteen in number, and bearing *ribs*; the *lumbar*, seven or six in the abdominal region; the *sacral*, three or four in the sacral region; and the *caudal*, about fifteen or sixteen in the tail.

Examining one of the anterior thoracic vertebræ first (Fig. 189), we see that the *centrum* (*c*) is continuous above with the *neural arch* (*n. a*), the lower part of which, on either side, presents an anterior and a posterior notch (*i. v. n*), so that when the vertebræ are in their natural position, an *intervertebral foramen* is formed for the passage of a spinal nerve. The roof of the arch is continued into a long *neural spine* (*n. sp*) projecting upwards and backwards, and just above the intervertebral notches are a pair of anterior and posterior *articular processes* or *zygapophyses* (*pr. z, pt. z*), which articulate synovially with the vertebræ next in front and behind respectively. The articular surface of each pre-zygapophysis looks upwards and inwards, that of the post-zygapophysis downwards and outwards. Arising laterally from either side of the arch is an outstanding *transverse process* (*t. pr*), on the under surface of which is an articular *tubercular facet* (*t. f*), with which the upper fork of the rib (p. 454) articulates. The lower fork or *head* of the rib articulates with a facet (*c. f*) formed partly by the anterior edge of the corresponding centrum just at the base of the neural arch, and partly by the posterior edge of the centrum next in front, so that each centrum bears half

a *capitular facet*, as it is called, on either side, both anteriorly and posteriorly (*c. f'*, *c. f''*). There are no free ribs in the vertebræ of other regions, in which, however, they are represented in the embryo, but early fuse with the corresponding transverse processes.

The first *cervical* vertebra, or *atlas* (Fig. 190, A), is ring-shaped, and its lower portion is narrow and unlike the other centra. The neural spine is small, and the transverse processes are broad horizontal plates, each perforated at its base by a *vertebrarterial canal* through which the vertebral artery runs. On the anterior face of the lateral parts of the atlas are two concave articular facets for articulation with the occipital condyles of the skull, and on its posterior face are two small facets for articulation with the second vertebra. The second cervical vertebra, or *axis* (Fig. 190, B), has its centrum produced anteriorly into a conical *odontoid process*, which fits into the lower part of the ring of the atlas and is held in its place by a ligament extending transversely across the latter : it is ossified from a distinct centre, which really belongs to the centrum of the atlas. The neural spine of the axis is elongated and compressed, and its transverse processes small and perforated each by a vertebrarterial canal; zygapophyses are present only on the posterior face of the arch. In all the other cervical vertebræ (Fig. 190, C), the transverse processes are also perforated by vertebrarterial canals, and, except in the seventh or last, are divided into dorsal and ventral lamellæ. The zygapophyses resemble those of the thoracic vertebra described above. The seventh cervical vertebra has a longer spine than the others, and bears a pair of half facets on the posterior surface of its centrum with which the first pair of ribs in part articulate.

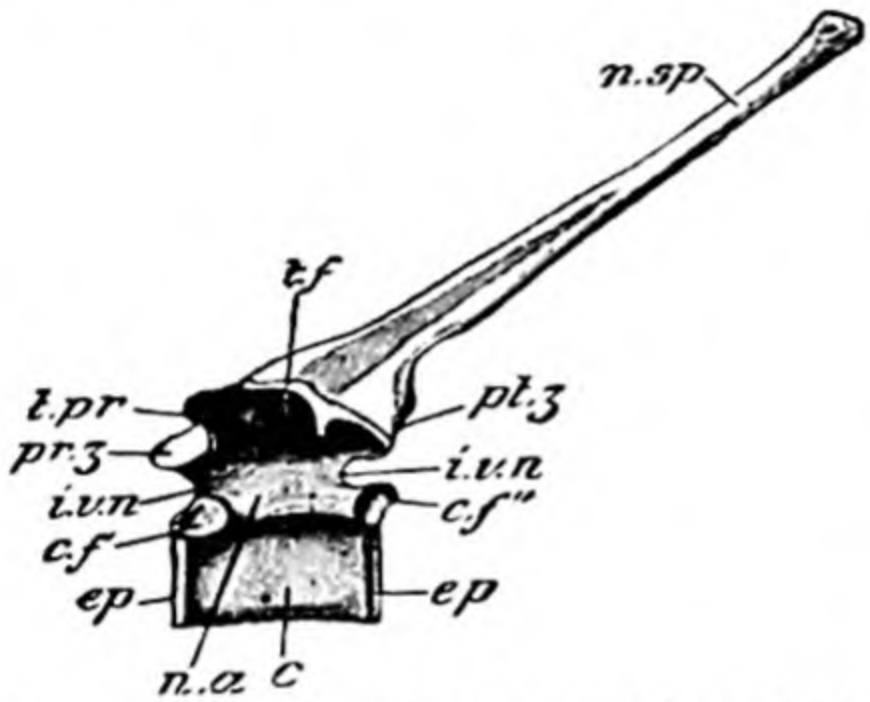


FIG. 189.—Fifth thoracic vertebra of the Rabbit, from the left side. (× 1½.)
c. centrum; *c. f'* capitular half-facet for fifth and *c. f''* for sixth rib; *ep.* epiphysis; *i.v. n.* intervertebral notch; *n. a.* neural arch; *n. sp.* neural spine; *pr. z.* pre-zygapophysis; *pt.z.* post-zygapophysis; *t. f.* tubercular facet for fifth rib; *t. pr.* transverse process.

A typical *thoracic* vertebra has already been described. In the tenth, the neural spine is vertical, and in the remaining two or three, which are larger than the others, it slopes forwards. In the posterior three or four there are no tuber-

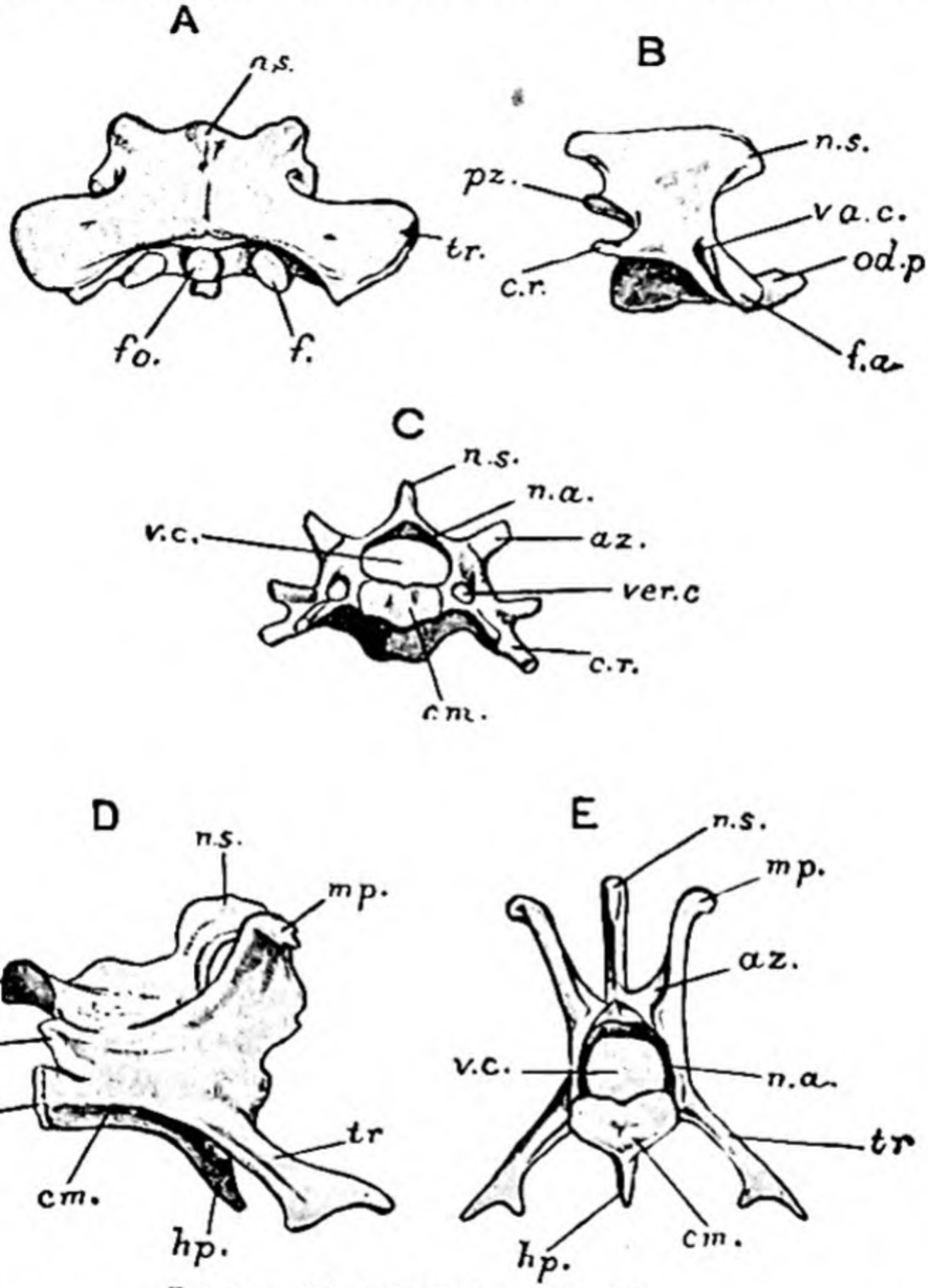


FIG. 190.—Selected vertebræ of Rabbit.

A, Atlas, from the dorsal surface; *B*, Axis, from the right side; *C*, one of the middle cervical vertebræ, anterior aspect; *D*, second lumbar vertebra, from the right side; *E*, the same, anterior aspect; *ap.* anapophysis; *c. r.* cervical rib; *f.* articular surfaces for the axis; *fa.* articular surfaces for the atlas; *fo.* facet for odontoid process; *hp.* hypapophysis; *mp.* metapophysis; *od. p.* odontoid process; *tr.* transverse process; *va. c.* or *ver. c.* vertebrarterial canal. Other letters as in the previous figure.

cular facets, the ribs in this region not being forked; the capitular facets are entire, and are situated on the corresponding centrum only. Additional processes are present above the pre-zygapophyses from the ninth thoracic vertebra onwards.

The *lumbar* vertebræ (Fig. 190, D and E) are relatively large, increasing in size from before backwards, and their various processes are greatly developed. The neural spines are directed upwards and forwards, the transverse processes are large and project outwards, downwards and forwards. As in the posterior thoracic vertebræ, there are stout processes above the pre-zygapophyses (which face *inwards*), and there is also a pair of more slender processes below the post-zygapophyses (which face *outwards*), and a median ventral process projecting downwards from the centrum in the first two.

The *sacral* vertebræ are fused to form the *sacrum* (Fig. 194, *sacr*), which supports the pelvic arch. The first —and to a less extent the second also—has large expanded, transverse processes which articulate with the ilia; these are the sacral vertebræ proper; the others, which decrease in size from before backwards, are really the anterior caudal vertebræ which fuse with the true sacral vertebræ to form a *compound sacrum*.

The more anterior *caudal* vertebræ resemble those of the sacral region, but on passing backwards all the processes are seen to diminish in size, until nothing but the centra are left at the end of the tail.

There are twelve or occasionally thirteen pairs of **ribs,** which have the form of curved rods, situated in the walls of the thorax, and articulating with the thoracic vertebræ above and—in the case of the first seven—with the breast-bone or sternum below: the remaining ribs do not reach the sternum (Fig. 191).

Each rib consists of a bony, dorsal *vertebral portion*, and of a ventral, *sternal portion* consisting of cartilage which is calcified or only incompletely ossified. The dorsal end—the head or *capitulum* of the rib—articulates with the capitular facets on the centra, and the first nine have also a *tubercle*, a short distance from the capitulum, which articulates with the tubercular facet; just externally to the tubercle is a short, vertical process.

The **sternum** (Fig. 191), which is developed in the embryo by the fusion of the ventral ends of the ribs (and therefore has a different morphological significance from the sternum of Amphibians, see p. 46), consists of six segments or *sternebræ*, the first of which, or *manu-*

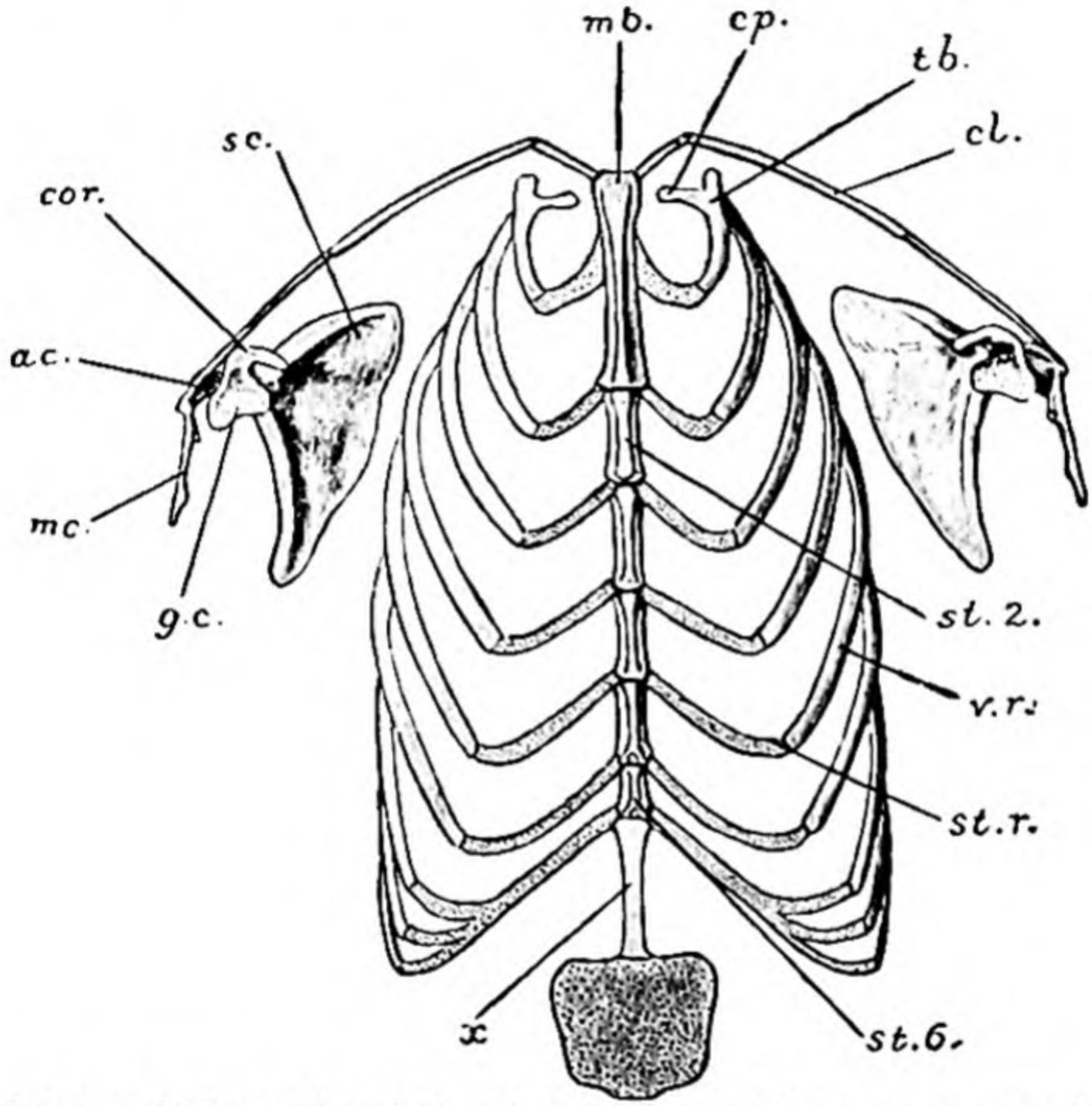


FIG. 191.—Sternum and pectoral arch of Rabbit, ventral aspect. *ac.* acromion; *cl.* clavicle; *cor.* coracoid process; *cp.* capitulum; *g. c.* glenoid cavity; *mb.* manubrium; *mc.* metacromion; *sc.* scapula; *st.* 6. sixth sternebra; *st. r.* sternal portion of a rib; *tb.* tuberculum; *v. r.* vertebral portion of a rib; *x.* xiphisternum with its cartilaginous plate. (After Borradaille.)

brium (*mb*), is larger than the rest, and has a ventral keel. With the last is connected a rounded, horizontal, cartilaginous plate, the *xiphisternum*. The ribs articulate between the successive sternebræ except in the case of

the first pair, the articulations of which are on the manubrium.

The chief bone of the **pectoral arch** is the flat, triangular *scapula* (Fig. 191, *sc*), the coracoid portion (compare p. 45) becoming early fused with it and forming a small, inwardly curved *coracoid process* (*cor*), situated anteriorly to the glenoid cavity at the lower end or apex of the scapula: the apex lies over against the first rib, and the bone inclines upwards and backwards to its dorsal base, which in the fresh condition consists of a strip of cartilage, the *suprascapula*. On its outer surface is a prominent ridge or *spine*, the free ventral edge of which is called the *acromion* (*ac*), from which a process, the *metacromion* (*mc*), projects backwards. The collar-bone or *clavicle* is never strongly developed in Mammals in which the fore-limb only moves in one plane—forwards and backwards: in the rabbit it is a small, curved, rod-like bone, attached by fibrous tissue at one end to the sternum and at the other to the acromion process of the scapula, there being small cartilages at either end of it.

The relative positions of the bones of the **fore-limb** are at first sight somewhat difficult to understand owing to their having become altered in the course of development. In your own fore-arm the bones can be rotated on one another, so that the thumb can be made to point outwards or inwards: while in the rabbit the first digit has permanently the same position, pointing inwards. To understand this, extend your arm outwards with the thumb pointing away from the ground. The back of the hand and arm, continuous with the dorsal surface of the body, or back, is its *dorsal surface*; the palm of the hand, and the surface of the arm continuous with the chest, is its *ventral surface*; the border of the arm and hand continuous with the thumb is the *preaxial border*; and that continuous with the little finger the *postaxial border*. This position is called the position of *supination*; if the fore-arm and hand be now rotated, so that the thumb points inwards, the position is that of *pronation*. While in this position, bend the elbow at right angles and bring

it inwards close to the body; the preaxial border of the hand will now be on the inner side, and an examination of the bones of the fore-arm shows that they cross one another. It is in this position that the bones of the rabbit's fore-limb are permanently fixed (Fig. 185, and compare Fig. 16).

The proximal extremity of the *humerus* (Fig. 192) bears a rounded *head* (*hd*) for articulation with the glenoid cavity, in front of which is a groove for the tendon of the biceps muscle (p. 58); certain *tuberosities* for the attachment of muscles will also be observed. Its distal extremity presents a large, pulley-like surface or *trochlea* (*tr*) for the articulation of the bones of the fore-arm, and a deep depression or *fossa*, perforated by a foramen, on its posterior side, for the reception of the end of the ulna. The *radius* (Fig. 193) is the shorter, inner (preaxial) bone of the fore-arm, and is slightly curved. Its head presents a large double surface for articulation with the trochlea of the humerus, and its distal extremity a pair of slight concavities for the bones of the carpus: the shaft is flattened where it abuts against the corresponding flattened surface of the *ulna* (Fig. 193). Near the proximal end of the last-mentioned bone is a cavity for the articulation of the humerus, and proximally to this, at the elbow, the ulna is produced to form a large *olecranon process* (*o. p.*), which is received into the fossa on the humerus when the limb is extended; its small distal end articulates with the carpus.

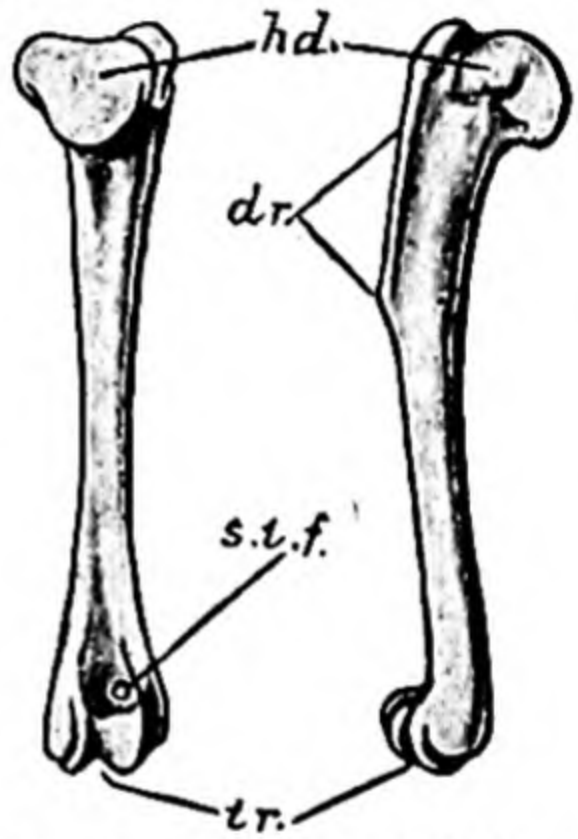


FIG. 192.—Humerus of Rabbit.
d. r. deltoid ridge; *hd.* head; *s.t. f.* supra-trochlear foramen; *tr.* trochlea.

The skeleton of the hand or *manus* consists of the *carpus*, the *metacarpus*, and the *phalanges*. The *carpus* (Fig. 193), as in the frog (p. 48), consists of a proximal and a distal row of small, nodular bones, which articulate with one another where they are in contact. The bones of the proximal row, beginning at the inner (preaxial) side, are the *radiale* (*r*) and *intermedium* (*i*) articulating with the radius, and the *ulnare* (*u*), articulating with the ulna. In the distal row are five bones, the middle one of which is distinctly proximal to the other four, so as really to lie in the middle of the carpus: this is the *centrale*, the others constituting a row of *distal carpals*. Of these the first three articulate with the corresponding digits, the fourth, on the outer (postaxial) side, supporting the fourth and fifth digits and really consisting of two carpals fused with one another.

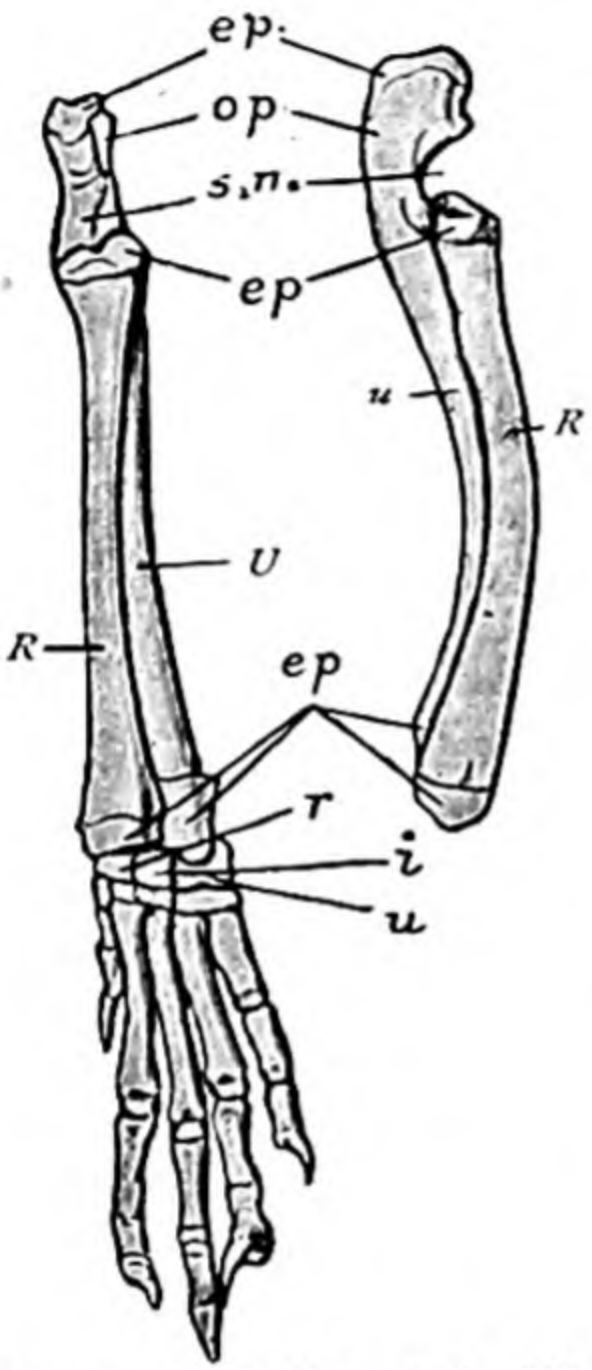


FIG. 193.—Radius and Ulna, Carpals, Metacarpals, and Phalanges of Rabbit.
ep. epiphyses; *i.* intermedium; *o. p.* olecranon process; *R.* radius; *r.* radiale; *s. n.* sigmoid notch; *U.* ulna; *u.* ulnare.

A small bone, the *pisiform*, articulating with the ulna and ulnare on the ventral side, is usually looked upon as a *sesamoid bone*, *i.e.*, an ossification in the tendon of a muscle; but it probably represents the vestige of a sixth digit.

Beyond the carpals (Fig. 193), there are five digits, each made up of a *metacarpal* and *phalanges*, articulating with one another. The innermost (preaxial) digit—the

thumb or *pollex*—is the shortest, and the third the longest: the former has two phalanges, the others three each, the distal or *ungual* phalanx of all the digits having a conical form, its dorsal surface being grooved for the firmer attachment of the horny claw.

The ends of the long bones in both limbs are separately ossified as *epiphyses* (compare p. 451), which eventually unite with the shaft of the bone in question. Small *sesamoid bones* are situated on the under or palmar side of the joints of the digits.

The **pelvic arch** (Fig. 194) consists of two lateral halves or *innominate bones*, the long axis of which is almost parallel with that of the vertebral column (Fig. 185), and which are firmly united anteriorly and internally with the transverse processes of the sacral vertebræ by a rough surface, while ventrally they are connected together by cartilage at the pelvic *symphysis*. On the outer surface of each innominate bone, at about the middle of its length, is a deeply concave cup, the *acetabulum*, for articulation with the head of the femur: in it, in young rabbits, a triradiate suture can be seen, marking the boundaries of the three bones of which the innominate is composed (p. 50).

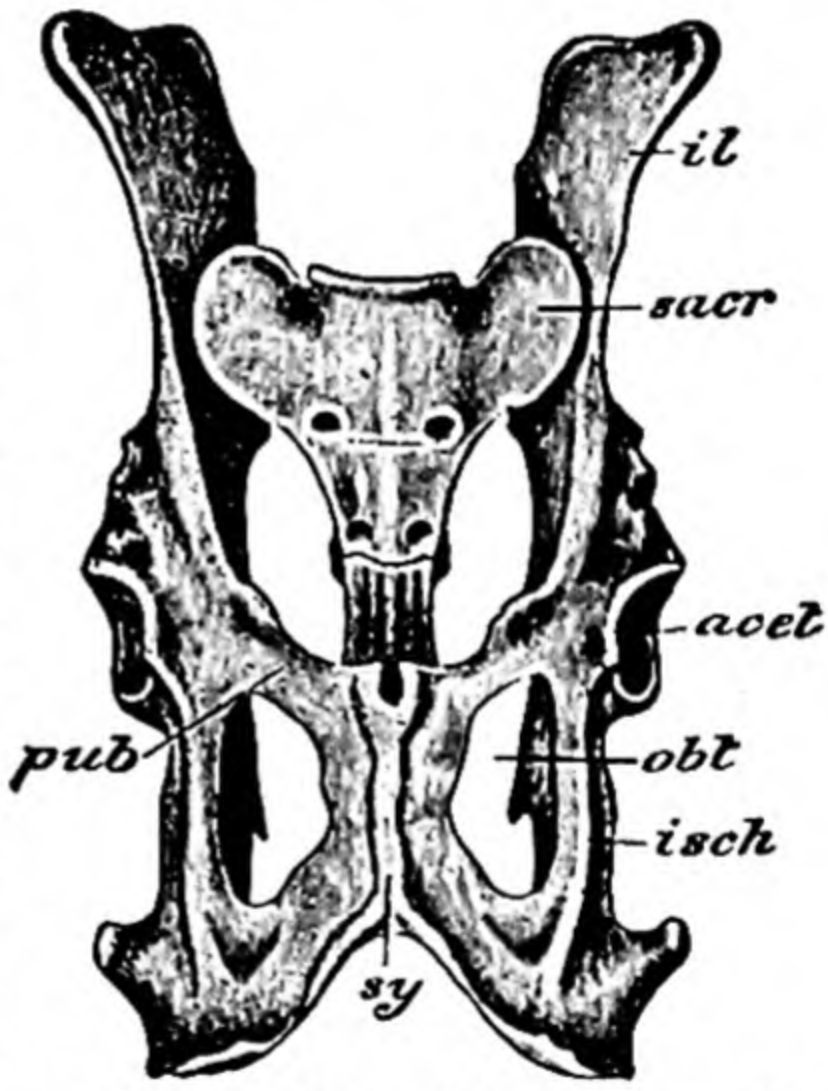


FIG. 194.—Pelvic girdle and sacrum of Rabbit, ventral aspect.
acet. acetabulum; *il.* ileum; *isch.* ischium; *obt.* obturator foramen; *pu.* pubis; *sacr.* sacrum; *sy.* symphysis. (From Parker and Haswell's *Zoology*.)

Of these, the antero-dorsal is the *ilium* (*il*), which is connected with the sacrum. The postero-ventral portion of the innominate is perforated by a large aperture —the *obturator foramen*, through which a nerve of that name passes (p. 492), the bone above and behind it being the *ischium* (*isch*), and that below and in front of it the *pubis* (*pu*). Behind the obturator foramen the ischium has a thickened posterior edge or *tuberosity*, and then curves round and becomes continuous with the pubis, both bones taking part in the symphysis.

The **hind-limb** has undergone rotation forwards (Fig. 185), so as to be brought, like the fore-limb, into a plane parallel with the median vertical plane of the body; but the rotation being forwards, and the bones of the shank not being crossed, the preaxial border is internal in the whole limb, and the original dorsal surface looks, on the whole, forwards.

Close to the proximal end of the *femur* (Fig. 195), on its inner (preaxial) border, is a rounded projecting *head* (*hd*) for articulation with the acetabulum: the actual end of the bone is formed by a strong process, the *great trochanter* (*tr.* 1), while just distal to the head is a *lesser trochanter* (*tr.* 2), and opposite this, on the outer (postaxial) side, a *third trochanter* (*tr.* 3). The distal end of the bone bears two large *condyles*, separated from one another by a notch, for articulation with the tibia: this notch is continuous with a groove extending for a short distance along the anterior (dorsal) surface of the femur in which a large sesamoid bone (p. 195), the knee-cap or *patella* (*p*), slides: the patella lies in the tendon of the extensor muscles of the leg, and is connected by ligament with the tibia. Two other sesamoid bones, the *fabellæ*, occur on the opposite side of the knee-joint.

The *tibia* (Fig. 195, T), or inner (preaxial) bone of the shank, is much larger than the *fibula* (Fig. 195, F), the

distal half of which in the adult becomes completely fused with it. The proximal end of the tibia bears two slightly concave articular surfaces for the condyles of the femur, and distally it articulates with the tarsus: a prominent ridge—the *cnemial crest*—extends along the proximal end of its anterior (dorsal) surface. The slender fibula is attached proximally to the tibia.

The skeleton of the foot or *pes* consists of the *tarsus*, the *metatarsus*, and the *phalanges*. The *tarsus* (Fig. 196) consists of six bones arranged in three rows. In the proximal row (compare p. 50) are two tarsals, of which the inner (preaxial) or *astragalus* (*t*) — probably corresponding to two bones fused together, the *tibiale* and *intermedium* — has a large pulley-like surface for articulation with the tibia; while the outer (postaxial) *calcaneum* or *fibulare* (*f*.) articulates with the fused end of the fibula, and is produced into a strong heel or *calcaneal process*. In the middle row is a single bone, the *centrale* (*navicular*) of the tarsus, and the distal row is made up of three bones, the true first, together with the corresponding digit (*hallux*), being absent as a distinct bone. The second (apparent first) distal tarsal articulates proximally

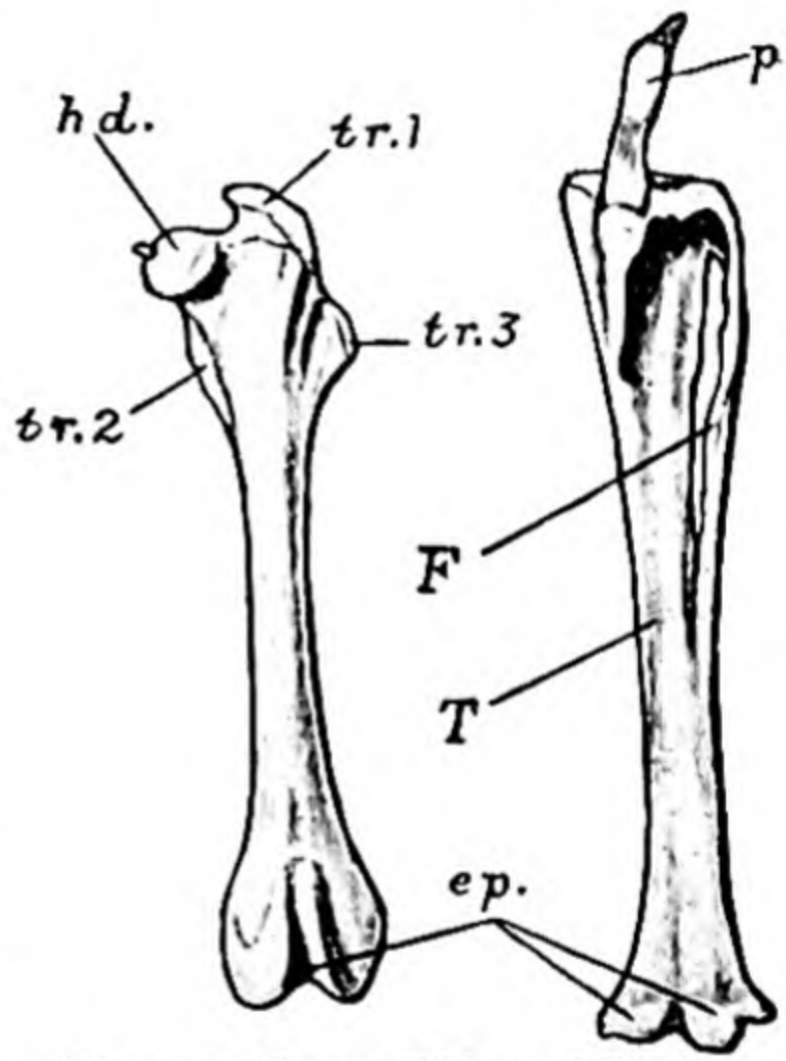


FIG. 195.—Femur, Tibia, and Fibula of Rabbit.

ep. epiphysis; F. fibula; *hd*. head; *p*, patella; T. tibia; *tr*. 1, greater trochanter; *tr*. 2, lesser trochanter; *tr*. 3, third trochanter.

with the centrale, and distally with the innermost (preaxial) metatarsal: the third (apparent second) with the centrale and the corresponding metatarsal: the fourth (apparent third), which corresponds to the two fused outer (postaxial) tarsals, with the centrale, calcaneum, and the remaining two digits.

Beyond the tarsus (Fig. 196) there are four *metatarsals* with their *phalanges*, of which there are three to each digit. The metatarsal of the hallux, together with the corresponding distal tarsal, is probably represented by a distinct ossification which in the adult becomes fused with the second (apparent first) metatarsal, and forms a process of that bone which articulates with the centrale. The phalanges are similar to those of the manus, and sesamoid bones are also present on the under surface of the foot.

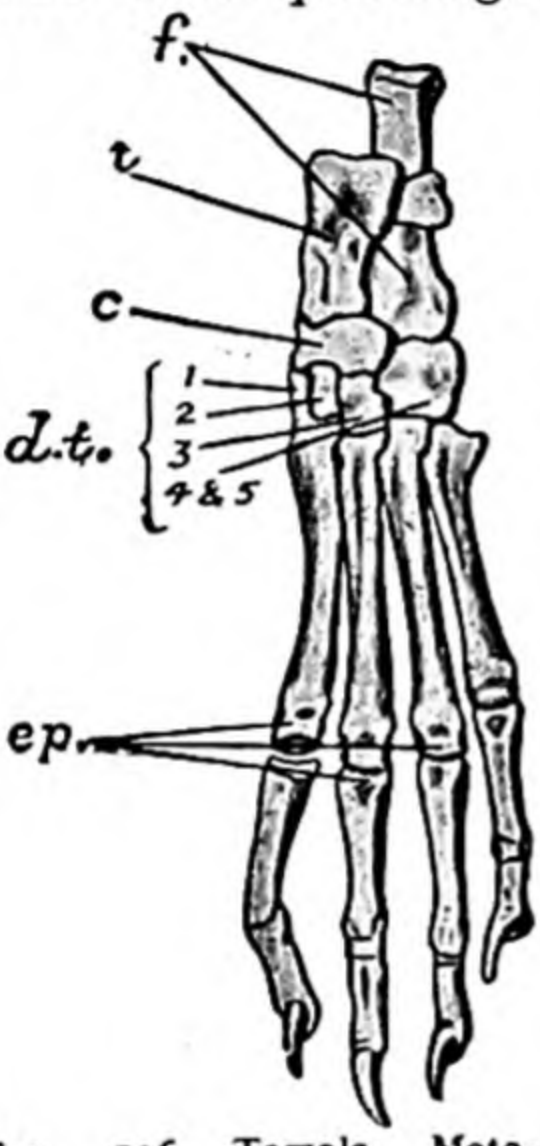


FIG. 196.—Tarsals, Metatarsals, and Phalanges of Rabbit.
c. centrale; *d. t.* 1, 2, 3, 4, and 5, distal tarsals; *ep.* epiphyses; *f.* fibulare (or calcaneum); *t.* tibiale (or astragalus).

Muscles and Body-wall.—It will be remembered that in the lancelet and dogfish the muscles of the trunk are divided up into myomeres (p. 411), while in the adult frog the only indication of such a segmentation of the muscles is seen in the recti of the abdomen. In the rabbit nearly all trace of a segmentation of the muscles has also disappeared, and the muscular system, although similar in its general arrangement to that of the frog (compare Fig. 3), is more highly differentiated and complicated. We shall have occasion to notice certain

of the muscles in the course of our examination of other organs.

Immediately beneath the skin, which consists of epidermis and dermis (Fig. 186), the whole ventral region of the trunk and neck is covered by a thin *cutaneous muscle*, by means of which the rabbit is able to twitch its skin. Internally to this muscle in the female are the *mammary glands* (p. 437), which, when secreting, appear as whitish branched masses, the ducts of which can be traced to the *teats*, on the apices of which they open by numerous small apertures.

A whitish band of connective-tissue passes along the mid-ventral line of the abdomen from the xiphisternum to the pubis : this separates two longitudinal bands of muscle, the *recti abdominis*, from one another; and laterally to them, the abdominal wall consists of three thin layers of muscle with their fibres running in different directions—the *external oblique*, the *internal oblique*, and the *transversalis*, the latter being lined on its inner surface by the peritoneum. A fibrous cord, known as *Poupart's ligament*, beneath which the blood-vessels and nerves pass outwards to the leg, extends upwards and forwards from each pubis to the corresponding ilium. In the thorax the muscles of the body-wall are broken up into separate portions by the ribs, and thus form a series of *intercostal muscles*, which, like the oblique muscles of the abdomen, are arranged in two layers, external and internal, and are important in respiration.

Extending from the thorax to the fore-limb of either side are the large *pectoral muscles*; and a number of other muscles can be seen in the neck, in the ventral middle line of which, covered by the cutaneous muscle, the windpipe or *trachea* is visible (Fig. 198). The trachea is strengthened by a series of cartilaginous rings and ends in front in the *larynx*, situated between the two rami of the mandible; and just in front of the larynx is the hyoid bone (p. 450), embedded in a mass of muscle.

The **Cœlome and its Contents.**—On cutting open the body-cavity (Fig. 197), it will be seen to be divided into

two main chambers—the *thoracic* and *abdominal cavities* —by means of the *diaphragm* (Fig. 197, B). The relatively

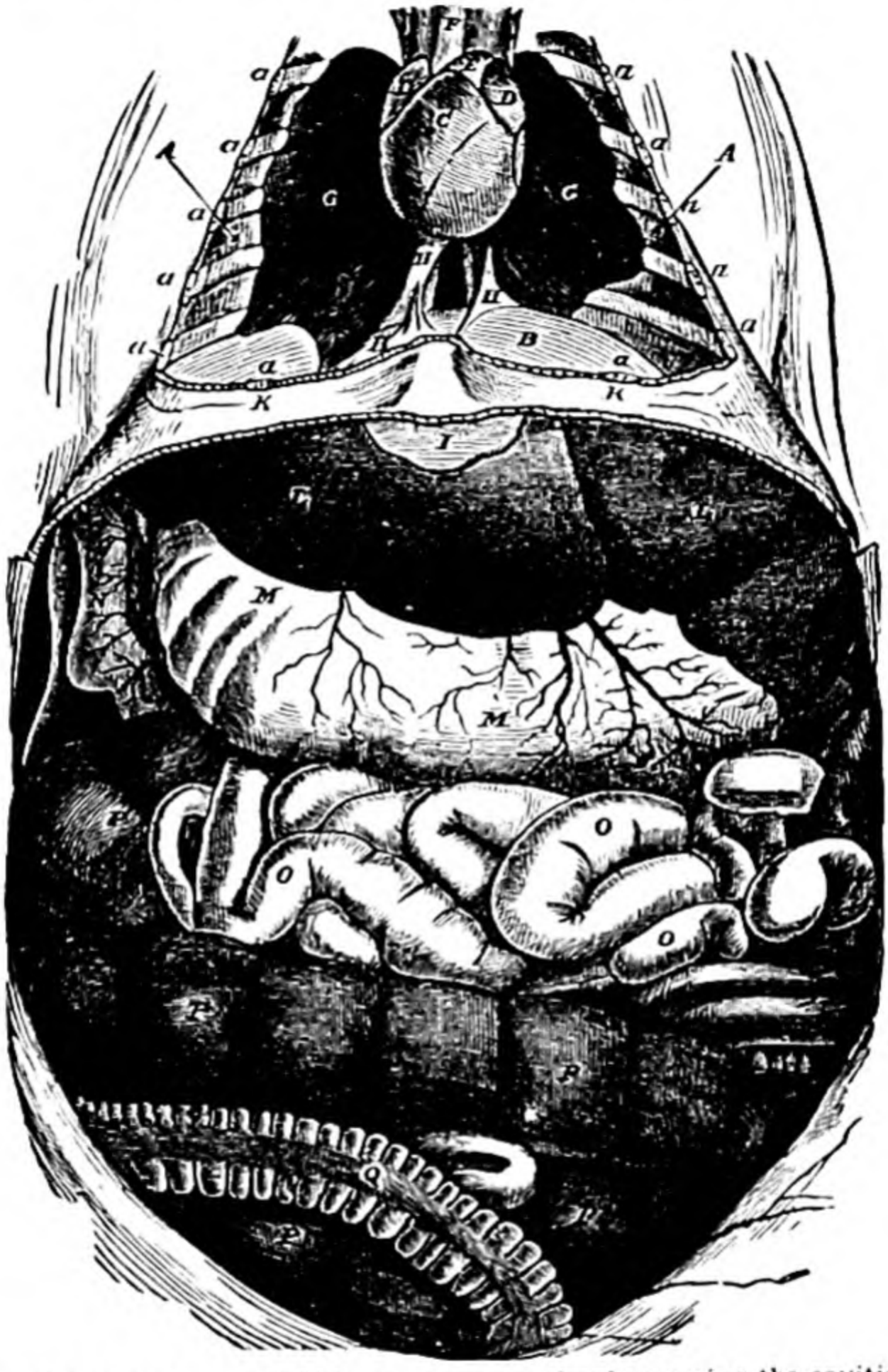


FIG. 197.—The viscera of a Rabbit as seen upon simply opening the cavities of the thorax and abdomen.

A. cavity of the thorax; *B*. diaphragm; *C*. ventricles of heart; *D*. auricles of heart; *E*. pulmonary artery; *F*. aorta; *G*. lungs, collapsed; *H*. part of pleura; *I*. cartilage at end of sternum; *K*. portion of body-wall left between thorax and abdomen; *a*. cut ends of ribs; *L*. liver; *M*. stomach; *N*. duodenum; *O*. small intestine; *P*. cæcum; *Q*. colon. (From Foster and Shore's *Physiology*.)

After entering the thorax, the trachea divides into two *bronchi*, one entering each lung and giving off branches to its different lobes: the bronchi, like the trachea, are supported by incomplete cartilaginous rings at their proximal ends, but these gradually disappear after the bronchi have entered the lungs.

The elastic *lungs* (Fig. 197, G) are not hollow sacs, like those of the frog, but are spongy bodies, of a light pink colour, situated on either side of and above the heart, and filling the greater part of the thoracic cavity, but collapsing as soon as the wall of the thorax is perforated. Each is subdivided into two *main lobes*, and the right lung has in addition two small *accessory lobes*, an anterior and a posterior, the latter lying in the median line, behind the heart, and being closely applied to the gullet.

Each pulmonary artery (Figs. 197, E, and 198, *p. a*) crosses the main bronchus anteriorly to the point at which it branches into the various lobes, except in the case of the anterior accessory lobe, the bronchus to which comes off in front of the artery and may even arise from the trachea before its bifurcation. Microscopic examination shows that the bronchi divide and subdivide to form a ramifying system of tubes, each ultimate branch of which opens into a minute chamber or *infundibulum*, which in structure closely resembles a frog's lung in miniature.

The parietal layer of the pleura (p. 465) lines the cavity of the thorax, and is reflected over each lung at the entrance of the bronchus to form the visceral layer: in the median line it forms a vertical partition, the *mediastinum*, with which it is continuous on the ventral side of the vertebral column above, and beneath the pericardium below (Fig. 202). Thus each lung (*l. lng*, *r. lng*) has its own separate *pleural cavity* (*l. pl*, *r. pl*), separated from its fellow by the right and left mediastinum, the space between which is called the *mediastinal*

space. The anterior and dorsal parts of this space are narrow, and enclose the posterior part of the trachea and the bronchi, as well as the gullet (*oes*) and main blood-vessels (*aort*, *az. v*, *pt. cav*); its middle part is wide, and encloses the heart (*l. vent*, *r. vent*), the mediastinum here fusing with the parietal layer of the pericardium (*par.*

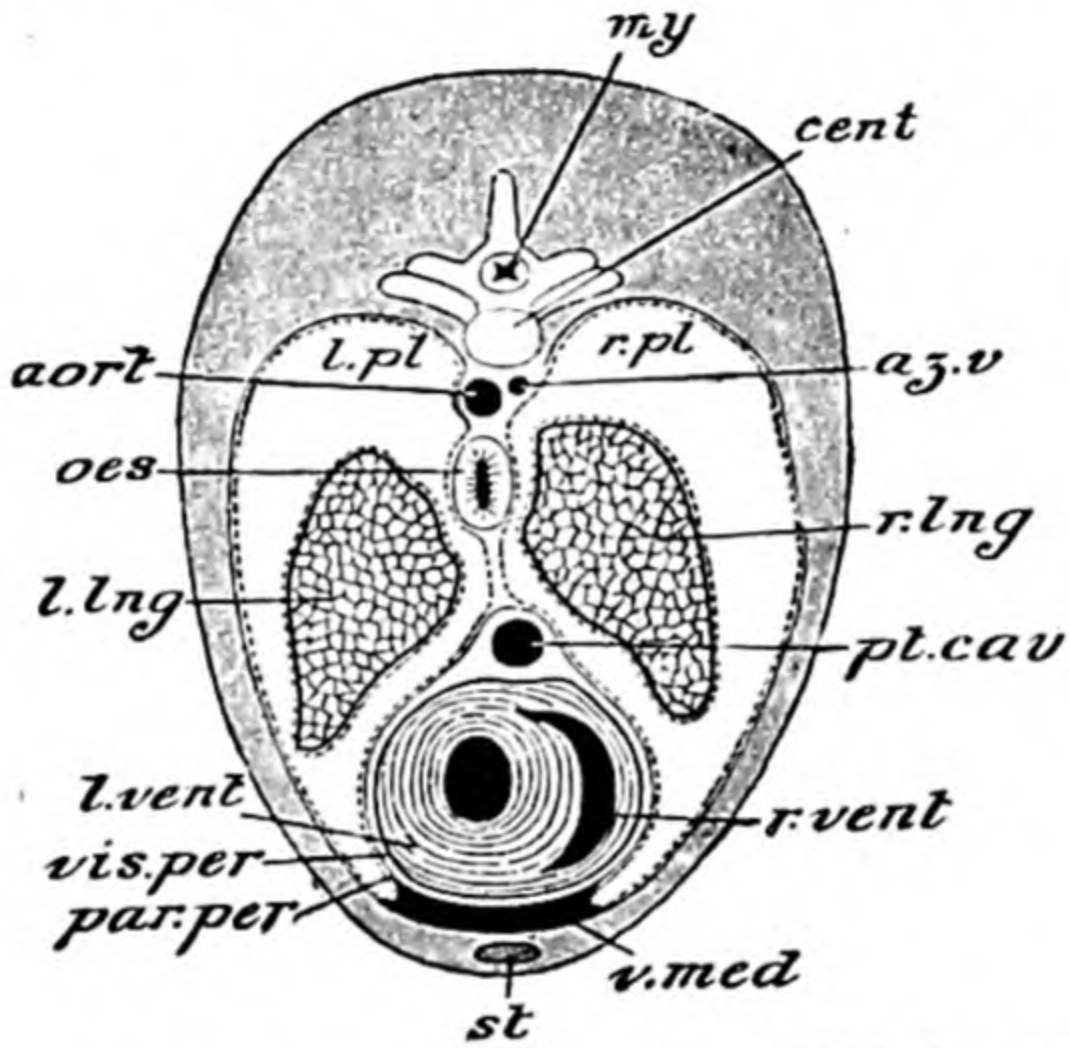


FIG. 202.—Diagrammatic transverse section of the Rabbit's thorax in the region of the ventricles, to show the relations of the pleuræ and mediastinum (dotted line), etc. The lungs are contracted. (× ⅝.)
aort. dorsal aorta; *az. v*. azygos vein; *cent*. centrum of thoracic vertebra; *l. lng*. left lung; *l. pl*. left pleural cavity; *l. vent*. left ventricle; *my*. spinal cord; *oes*. gullet; *par. per*. parietal layer of pericardium; *pt. cav*. postcaval, close to its entrance into right auricle; *r. lng*. right lung; *r. pl*. right pleural cavity; *r. vent*. right ventricle; *st*. sternum; *vis. per*. visceral layer of pericardium; *v. med*. ventral mediastinal space. (From Parker and Haswell's *Zoology*.)

per) and thus obliterating the space; below this it again narrows to form the ventral mediastinal space (*v. med*), in which the thymus (p. 465) is situated.

In the entire animal, the air-tight pleural cavities are completely filled by the lungs, so that the parietal and visceral layers of the pleuræ are practically in contact, there being only a lubricating serous fluid (lymph)

the frog (p. 146), two others—the *spinal accessory* and the *hypoglossal* (represented in the frog by fibres in connection with the vagus and by the first spinal nerve respectively, p. 143)—emerge from the skull and are therefore counted as the eleventh and twelfth cerebral nerves. The former arises from the side of the medulla oblongata and the spinal cord by numerous fibres, the posterior of which are opposite the fifth spinal nerve, from which point it runs forwards between the dorsal and ventral roots and leaves the skull together with the glosso-pharyngeal and vagus (p. 449), supplying certain muscles of the neck and shoulder. The hypoglossal arises by a number of fibres from the ventral surface of the medulla oblongata, passes out through the condylar foramen, curving forwards round the angle of the jaw to supply the muscles of the tongue, and sending a branch backwards, known as the *ramus descendens* (Fig. 205, *r. d*) which goes to certain muscles of the neck.

The relations of the **sympathetic nerves** are also essentially similar to those occurring in the frog (p. 145). Each passes backwards along the neck (Fig. 205, *c. sy.*) close to the vagus (*vg*) and alongside the carotid artery, enlarging to form an anterior and a posterior cervical ganglion (*s. c. g, i. e. g*). In the thorax it runs just beneath the heads of the ribs, having a ganglion in each intercostal space: it then passes into the abdomen, lying close to the centra of the vertebræ and having ganglia at intervals. From all the sympathetic ganglia branches are given off connecting them with the spinal nerves (*rami communicantes*), others going to the blood-vessels: others again, in the thorax and abdomen, are connected with plexuses from which nerves pass to the heart and abdominal viscera.

In the thorax two large *splanchnic nerves* run off from the cords and, piercing the diaphragm, fuse with a large

cœliac ganglion, placed in the mesentery just in front of the origin of the anterior mesenteric artery, and united with an *anterior mesenteric ganglion* just behind it. From these ganglia numerous branches run off to the abdominal viscera. These ganglia and nerves are together spoken of as the *cœliac plexus*.

Sensory Organs.—The sense of touch is situated in microscopic *tactile organs* in the skin, and groups of cells, called *taste-buds*, are present on the papillæ of the tongue (p. 466) and on the soft palate (compare pp. 161 and 162).

The *organs of smell* are situated in the olfactory capsules, the form of which has already been described (p. 446). They open externally by the *external nostrils*, and are produced backwards above the palate into the passage of the *internal nostrils*, which communicate with the naso-pharynx (p. 469). The olfactory epithelium, supplied by the olfactory nerves, is situated on the ethmo-turbinal (*e. tb*) : the mucous membrane of the maxillo-turbinal (*m. tb*) probably serves merely to warm the inspired air.

On the ventral side of the nasal septum is a pair of small, tubular structures known as the *vomero-nasal* or *Jacobson's organs*, lined by epithelium and enclosed in cartilages situated just to the inner side of the palatine processes of the premaxillæ (p. 448). The function of these organs is not understood.

The structure of the *eye* (Fig. 209) is similar to that already described in other Vertebrates (p. 163) except that the sclerotic is not cartilaginous, but is composed of dense fibrous tissue, and the lens is relatively smaller than in the frog and is markedly biconvex in form, the outer surface being rather flatter than the inner : it is capable of adjustment by means of the *ciliary muscle*. This is a continuous ring of delicate muscle consisting of fine unstriped fibres arising from the junction of the sclerotic and cornea and passing backwards into the

ciliary processes (Fig. 209, CP). These are a series of folds or plaits arranged in a radiating manner all round, into which the choroid is thrown just externally to the iris (compare p. 166).

When the ciliary muscle contracts, it pulls the ciliary

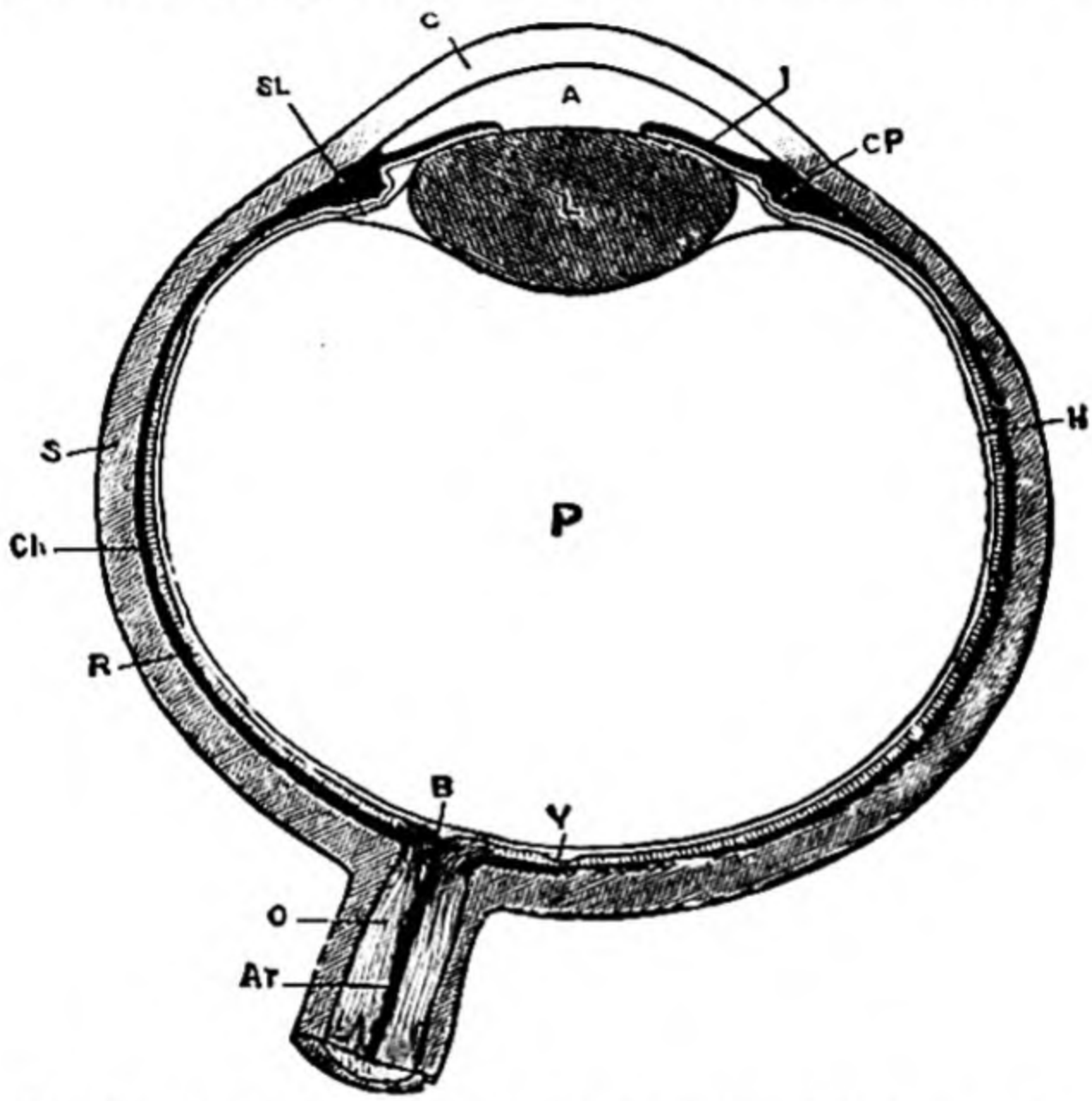


FIG. 209.—A diagrammatic transverse section through the Human Eye.
A. anterior chamber; *Ar*. central artery of the retina; *B*. blind spot; *C*. cornea; *Ch*. choroid; *CP*. ciliary processes; *H*. hyaloid membrane enclosing the vitreous humour; *I*. iris; *L*. lens; *O*. optic nerve; *P*. posterior chamber; *R*. retina; *S*. sclerotic; *SL*. suspensory ligament; *Y*. yellow spot. (There is no yellow spot in the eye of rabbit.)

processes with the loosely attached choroid forwards towards the origin of the muscle. The ciliary processes carry the attachment of the suspensory ligament with them nearer to the lens, the whole suspensory ligament being thus slackened. In looking at a near object the ciliary muscle contracts, and so slackens the suspensory ligament, and the pressure on the anterior surface of the lens being lessened, it becomes more convex by its own elasticity. This

power of adjustment for objects at varying distances from the eye is called accommodation.

The eyelids have already been described (p. 440). The four *recti muscles* ensheath the optic nerve, as in the frog (p. 168), but the *superior oblique*, instead of arising—like the *inferior oblique*—in the anterior part of the orbit, takes its origin further back, near the recti, passes forwards through a fibro-cartilaginous pulley at the anterior angle of the orbit, and then backwards and outwards to its insertion on the eyeball.

Between the wall of the orbit and the eyeball are two glands, the secretion of which, passing through ducts perforating the conjunctiva lining the eyelids, serves to keep the outer surface of the eye moist, and is then conducted into the nasal chambers by means of the naso-lacrymal duct (pp. 168 and 447). These two glands correspond to special differentiations of a primarily continuous structure : one, the *Harderian gland*—already met with in the frog—is situated in the antero-ventral region of the orbit : the other, or *lacrymal gland* proper, in its postero-dorsal region. Besides these, a series of small *Meibomian glands* is present on the inner side of the edges of the eyelids, and produces a fatty secretion.

The ear or the *auditory organ* is extremely complicated, and consists of three parts, viz., the external ear, the middle ear, and the internal ear. The *external ear* consists of the pinna (p. 440) and the auditory passage (Fig. 210, Ex) leading to the drum or the *tympanic membrane* (M), which is situated obliquely at the boundary of the tubular and bulbous portions of the tympanic bone, separating the external ear from the middle ear.

The *middle ear* is constituted by the tympanic cavity in the tympanic bulla, and communicates with the pharynx by the Eustachian tube (Fig. 210, E). Its external boundary is formed by the tympanic membrane, which is raised inwards like the roof of a tent, and is kept

on the stretch by a small muscle. The tympanic cavity is crossed by a chain of three small bones known as the auditory ossicles, viz., the hammer-shaped *malleus*, the anvil-shaped *incus*, and the stirrup-shaped *stapes* (p. 446). The *malleus* (O_3) is attached by its handle-like process to the inner surface of the tympanic membrane,

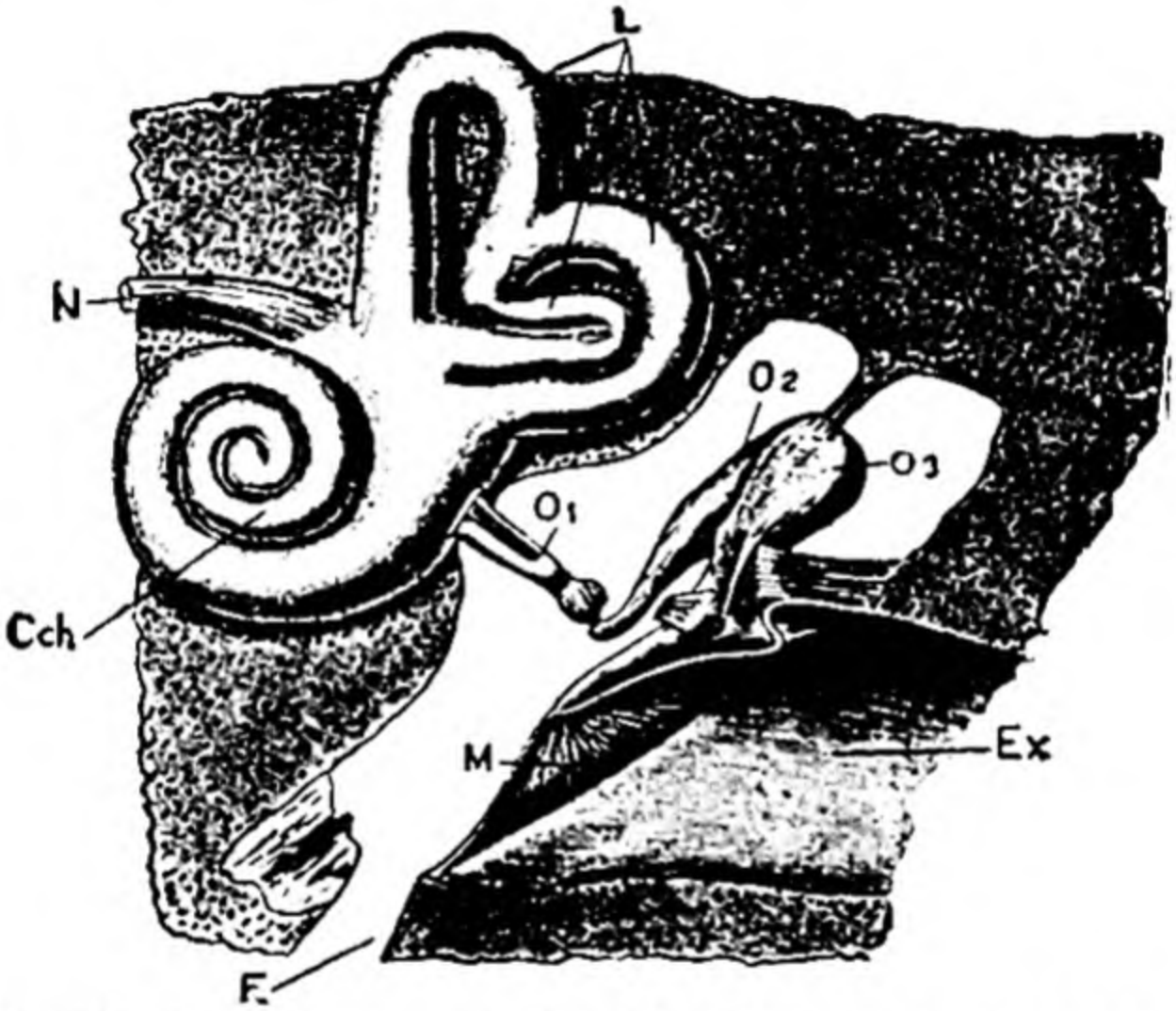


FIG. 210.—Diagram of the mammalian bony labyrinth, tympanic cavity, and external auditory passage.

Cch. bony cochlea; *E*. Eustachian tube; *Ex*. external auditory passage; *L*. bony semicircular canals; *M*. tympanic membrane; *N*. auditory nerve; O_1. stapes; O_2. incus; O_3. malleus. (After Headley.)

and its head articulates with the body of the *incus* (O_2), a process of the latter bone articulating through the intermediation of a small bony nodule, with the *stapes* (O_1). The inner end of the latter fits into the fenestra ovalis of the periotic bone (p. 446). The chain of ossicles serve to convey the vibrations of the tympanic membrane to the internal ear. Morphologically, the stapes corre-

sponds to part or the whole of the frog's columella (Fig. 12).

The study of development indicates that the malleus corresponds to the ossified articular part of the mandibular cartilage of lower Vertebrates, and the incus to the quadrate (pp. 41 and 431): the articulation of the bony mandible with the squamosal in Mammals has rendered these parts unnecessary for their original purpose; and they have undergone a *change of function*, forming an accessory part of the auditory apparatus.

The *internal ear* or the essential part of the auditory organ consists, as in other Vertebrates, of the *membranous labyrinth* with its three *semicircular canals* (p. 169) enclosed in the auditory capsule (periotic bone, p. 445). The small outgrowth of the sacculus seen in the frog, and known as the *cochlea* (Fig. 62, *cc*), is represented by a relatively larger structure, coiled on itself in a spiral manner, and especially important as regards the sense of hearing. The part of the periotic bone which directly surrounds the cavity in which the membranous labyrinth lies is especially hard, and when the outer portion of the bone is cut away, is seen to form a sort of cast of the enclosed organ, the form of which it repeats: this is known as the *bony labyrinth* (Fig. 210). Internally it is separated from the membranous labyrinth by a narrow space all round, containing the perilymph (p. 171) and only shut off from the tympanic cavity at the fenestra ovalis and fenestra rotunda (p. 446) by the membrane which closes each of them.

The membranous cochlea does not run up in the centre of the bony cochlea, but is attached between its outer wall and a shelf projecting inwards into the cavity, from its inner wall. Thus a transverse section through a coil of the cochlea shows three passages, the upper *scala vestibuli*, the lower *scala tympani*, and the *scala media* or membranous cochlea between the two. On the floor of the membranous cochlea lies the real terminal apparatus of the sense of hearing, called

The brain has reached a higher degree of differentiation than in any other class of Vertebrates. The two cerebral hemispheres, in all except the Prototheria and Marsupials (see below), are connected together by a band of transverse fibres, the corpus callosum, not represented in the other Vertebrates. The dorsal part of the mid-brain is divided into four optic lobes, the corpora quadrigemina. On the ventral side of the hind-brain is a transverse band of fibres, the pons Varolii, by which the lateral portions of the cerebellum are connected together.

The kidneys are derived from the metanephros, and the ureters, except in Prototheria, open into the bladder, and not directly into a cloaca.

With the exception of the Prototheria, mammals are all viviparous. In all the higher mammals the ova are minute, and after fertilization are retained in the uterus, in which each develops into a fœtus. The fœtus is nourished from the blood system of the parent through a special development of the allantois and the lining membrane of the uterus, termed the placenta. After birth, the young ones are nourished for a longer or shorter period by the milk or secretion of the mammary glands of the parent.

Classification.—The class Mammalia is divided into three primary divisions or sub-classes, which are called :—

I. Prototheria, or primitive mammals.
II. Metatheria, or modified mammals.
III. Eutheria, or perfect mammals.

The **Prototheria** include two extraordinary animals, the Duck-billed Mole and the Spiny Ant-eater, which are found only in Australia, New Guinea, and Tasmania. In these animals large eggs containing abundant yolk and with a firm shell are laid in a nest and incubated by the

mother. The oviducts are large and separate throughout, opening along with the intestine into a common cloaca, as is the case with Birds and Reptiles. The ureters do not open into the bladder as they do in all other Mammalia, but they, as well as the bladder, open separately into the cloaca. After they are hatched the young receive milk from the mother. There is no teat, but the fluid from the mammary glands seems to soak into the hair, and thence is sucked by the young. These

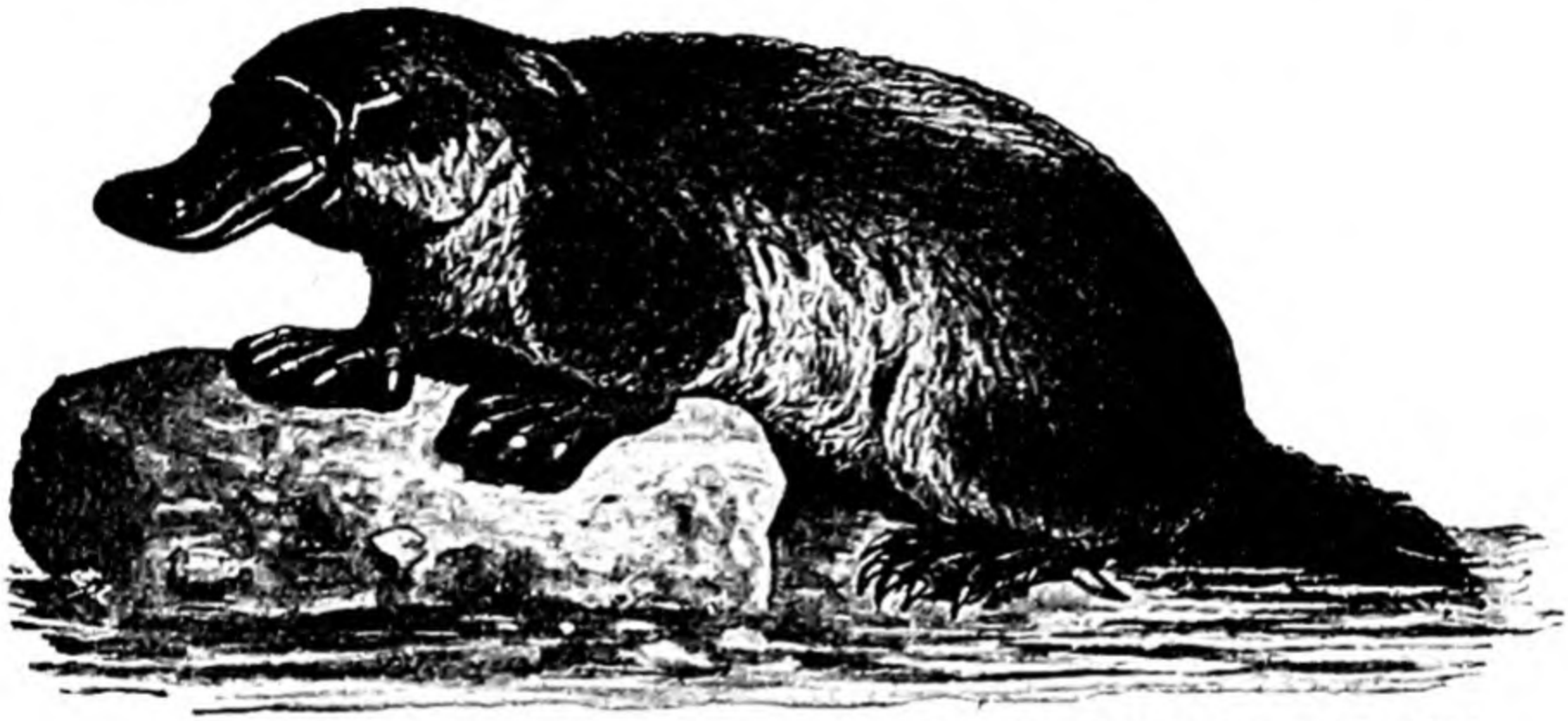


FIG. 216.—Duck-billed Mole (*Ornithorhynchus anatinus*). (After Vogt and Specht.)

animals are of great interest from an evolutionary point of view, as showing many affinities with the Reptiles, from some of which the great group of Mammals is believed to have been evolved. The skeleton also presents many interesting features of agreement with the Reptiles; there are large coracoids articulating with the sternum, a T-shaped episternum, and a pair of epipubic (marsupial) bones.

The section **Metatheria** includes all the pouch-bearing mammals, such as the Opossums of America, and the Dasyures, the Bandicoots, the Wombats, the Phalangers,

and the Kangaroos of Australia and the neighbouring islands. In these animals the egg is very small, and the ovarian tube is divided into an upper part of narrow

FIG. 217.—The Rock Wallaby (*Petrogale xanthopus*) with young in pouch. After Vogt and Specht.)

diameter called the Fallopian tube and a lower, wider part called the uterus. In the uterus the small egg is retained for some time and develops a close adhesion to its wall for obtaining nourishment.

The young are born in a rudimentary and helpless condition and are placed by the mother in a pouch formed by a fold of skin on the lower part of her body, whence the name Marsupials (Lat. *marsupium*, a pouch) often given to these animals. The young are quite incapable of feeding themselves, but each becomes attached by its mouth to the opening of one of the ducts of the milk-gland, and the mother squeezes the milk-gland by compressing the muscles of the belly and thus forces milk down their throats. These animals also, like the Prototheria, possess a pair of epipubic (sesamoid) bones running forward from the pubes.

The highest division of the mammals, the **Eutheria,** comprise the great majority of mammals. In them the egg is exceedingly small. The first part of the oviduct is narrow, but the uterus is greatly enlarged, and the egg not only remains there for a long time, but as the fœtus is developing, a special organ, called the *placenta*, is formed. This organ is the result of a great development of the allantois, which grows out and becomes interlocked with depressions in the wall of the uterus. The middle portions of the oviducts, or uteri, are sometimes quite separate, as in the rabbit (p. 504), sometimes partly united, as in the cat, rarely completely united, as in monkeys and man. The third part of the oviducts are, however, completely joined and form a single passage, the vagina.

Leaving aside the fossil forms, the Eutheria are usually arranged in the following eleven orders :—

1. *Edentata*, comprising the Sloths, Ant-eaters, and Armadillos of South America.

2. *Effodientia*, the Scaly Ant-eaters and the Cape Ant-eaters of Africa.

3. *Insectivora*, including the Moles, Shrews, and Hedgehogs.

4. *Carnivora*, or the Cats, Dogs, Bears, Otters, and the Seals and Walruses.

5. *Cetacea*, including the Whales, Porpoises, and Dolphins.

6. *Ungulata*, a very large order, comprising, among other forms, the Horses, Tapirs, and Rhinoceroses, the Ruminants (Camels, Oxen, Sheep, Goats, Antelopes, Giraffes, and Deer), the Pigs and Hippopotami, and the Hyraxes.

7. *Proboscidea*, or the Elephants.

8. *Sirenia*, or Dugongs and Manatees (Sea-cows).

9. *Rodentia*, a large order, including, among others, the Rats and Mice, Hares and Rabbits, Squirrels, Beavers, and Porcupines.

10. *Chiroptera*, or Bats, and Fruit-eating Bats ("Flying Foxes").

11. *Primates*, comprising the Lemurs, Monkeys, Baboons and Apes, and Man.

We cannot enter here into a description of the structural peculiarities exhibited by members of all these orders, but there are certain points of organization which even an elementary student of Zoology may like to make acquaintance with. We shall therefore deal with some of the more important features in the following pages, which, it is hoped, will enable him to understand better the Doctrine of Evolution, dealt with in a subsequent chapter (pp. 584 *et seq.*).

The **Carnivora** are distinguished above all by their teeth. Their incisors are small and insignificant, but their canines (teeth which are quite absent in a typically herbivorous mammal like the rabbit) are large and pointed, and it is with these the animal seizes and kills its prey. The premolars have cutting edges, and the molars are mostly broad and crushing. The last premolar in the upper jaw and the first molar in the lower

jaw are very large and blade-like, and bite on one another like a pair of scissors, and are called the carnassial teeth. The skull of the Dog, on account of its larger size, is sometimes substituted for that of the Rabbit for detailed study of a mammalian skull; and in any case it would be a most useful exercise for a student after having studied the skull of the Rabbit (pp. 441–450) to trace out the various bones and find the different foramina on the skull of the Dog, noting any points of difference that he may come across. For this study no separate description is required, as the figures here given will afford all the help the student may need.

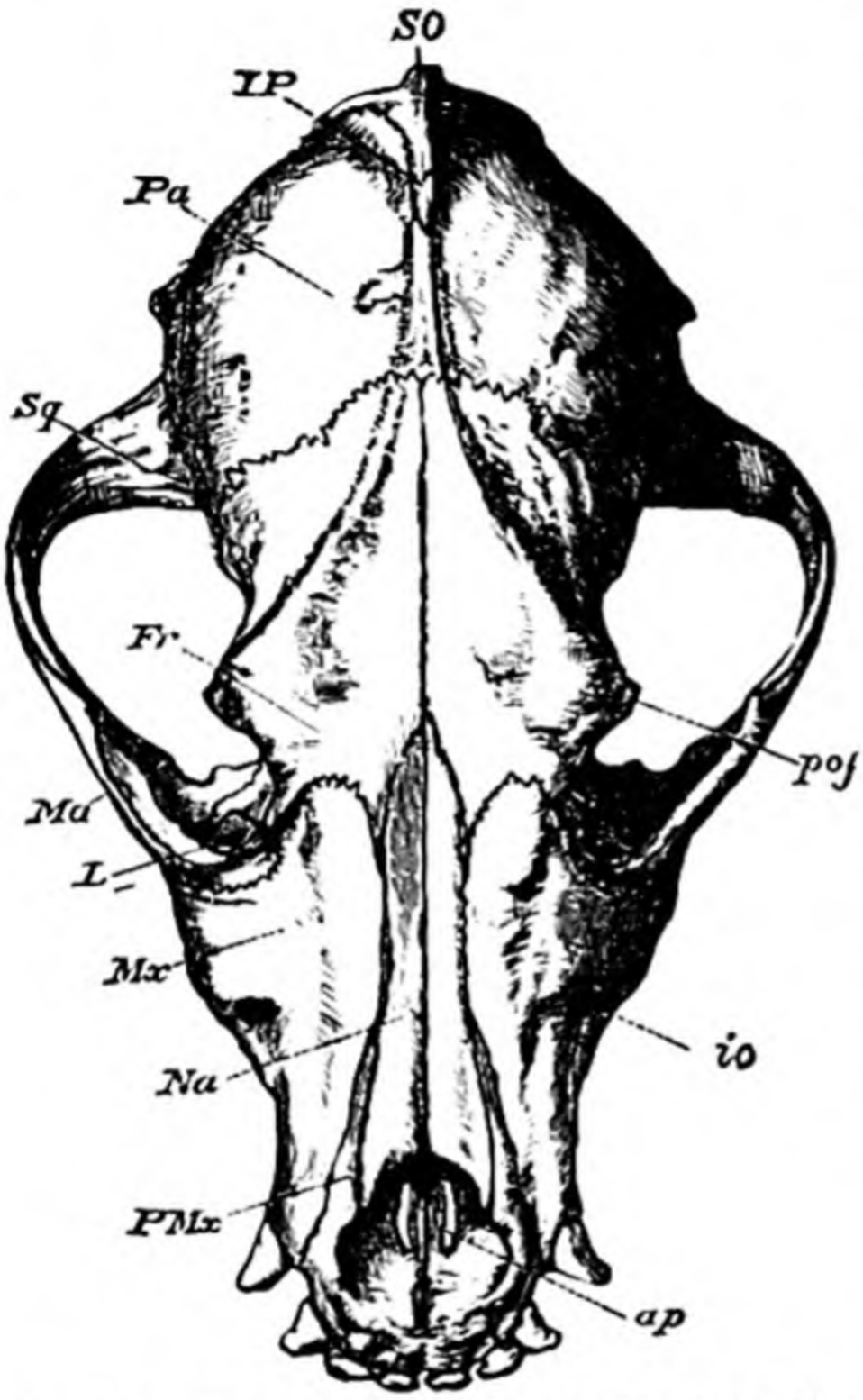


FIG. 218.—Dorsal view of the cranium of a Dog (*Canis familiaris*), half natural size.
So. supra-occipital; *IP.* inter-parietal; *Pa.* parietal; *Sq.* squamosal; *Fr.* frontal; *L.* lacrymal; *Ma.* malar or jugal; *Mx.* maxilla; *Na.* nasal; *Pmx.* premaxilla; *ap.* anterior palatine foramen; *io.* infra-orbital foramen; *pof.* postorbital process of frontal bone. (From Flower's *Osteology of the Mammalia.*)

As special features in which the skull of Dog differs from that of Rabbit might be mentioned the prominent sagittal and lambdoidal crests, the deep temporal fossæ,

the strong and greatly arched zygoma, and the greater development of the facial region. The glenoid cavity

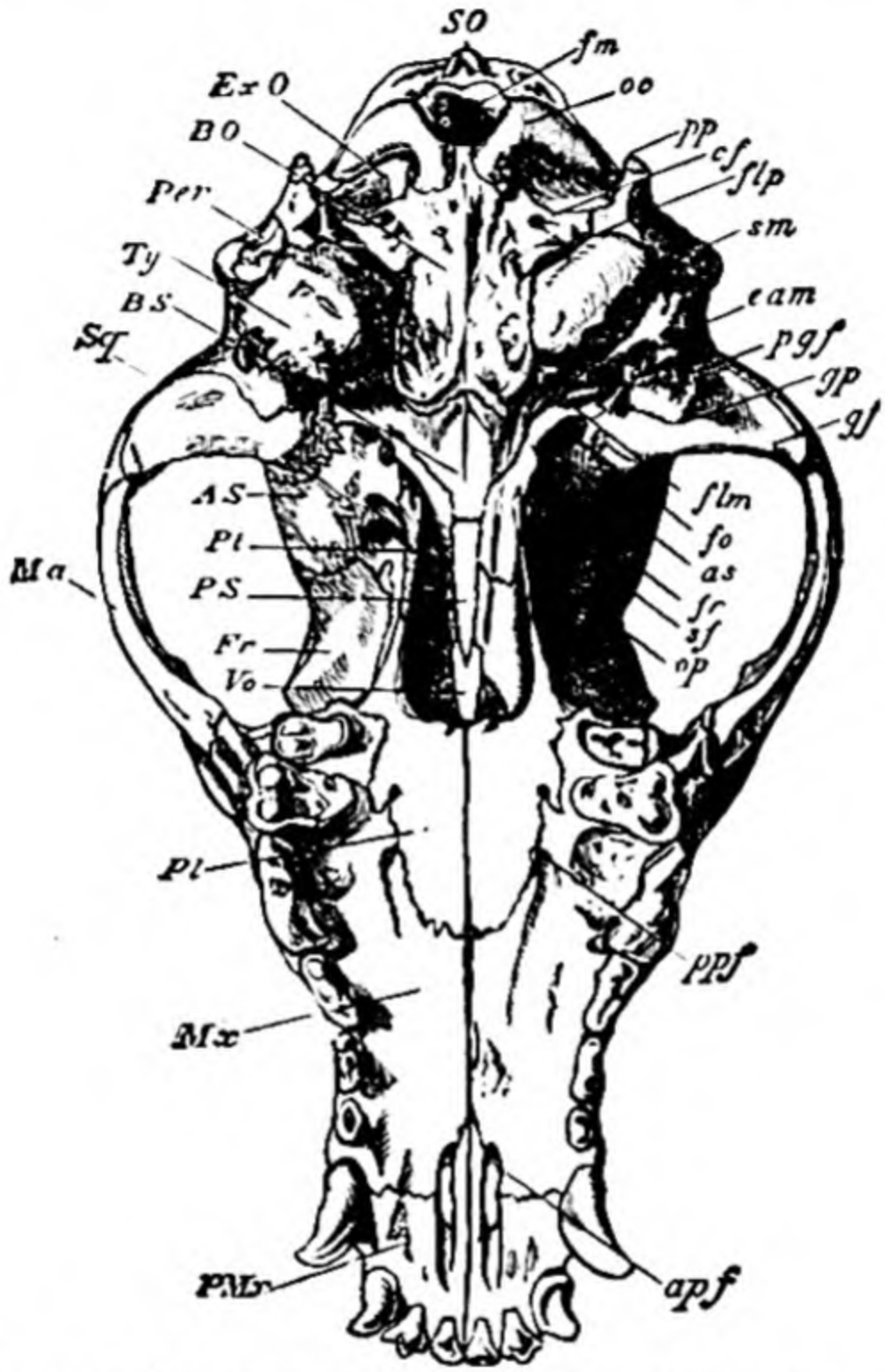


FIG. 219.—Ventral view of the cranium of a Dog, half size.
Exo. exoccipital; *BO.* basioccipital; *Per.* mastoid portion of periotic; *Ty.* tympanic bulla; *BS.* basisphenoid; *Sq.* zygomatic process of the squamosal; *As.* alisphenoid; *Pt.* pterygoid; *Ps.* presphenoid; *Vo.* vomer; *Pl.* palatine; *fm.* foramen magnum; *oc.* occipital condyle; *pp.* paroccipital process; *cf.* condylar foramen for the XII nerve; *sm.* stylomastoid foramen for the exit of the VII nerve; *eam.* external auditory meatus; *pgf.* postglenoid foramen; *gp.* postglenoid process; *gf.* glenoid fossa; *flm.* foramen lacerum medium, through which the internal carotid passes to the brain; *fo.* foramen ovale, for the exit of the mandibular division of the V nerve; *as.* posterior opening of alisphenoid canal (through which external carotid artery runs for part of its course); *fr.* foramen rotundum (for the maxillary division of the V nerve) and anterior opening of alisphenoid canal; *sf* sphenoidal fissure or foramen lacerum anterius for III, IV, ophthalmic division of V, and VI nerves; *op.* optic foramen for II nerve; *ppf.* posterior palatine foramen. Other letters as in the preceding figure. (From Flower's *Osteology of the Mammalia.*)

is in the form of a transverse groove to the shape of which the transversely elongated condyle of the mandible is adapted. The dental formula is $i\ \frac{3}{3}\ c\ \frac{1}{1}\ pm\ \frac{4}{4}\ m\ \frac{2}{3} = 42$.

Among the members of this order, the ends of the digits are provided with curved claws, which may be very long and sharp, and are capable, when not in use,

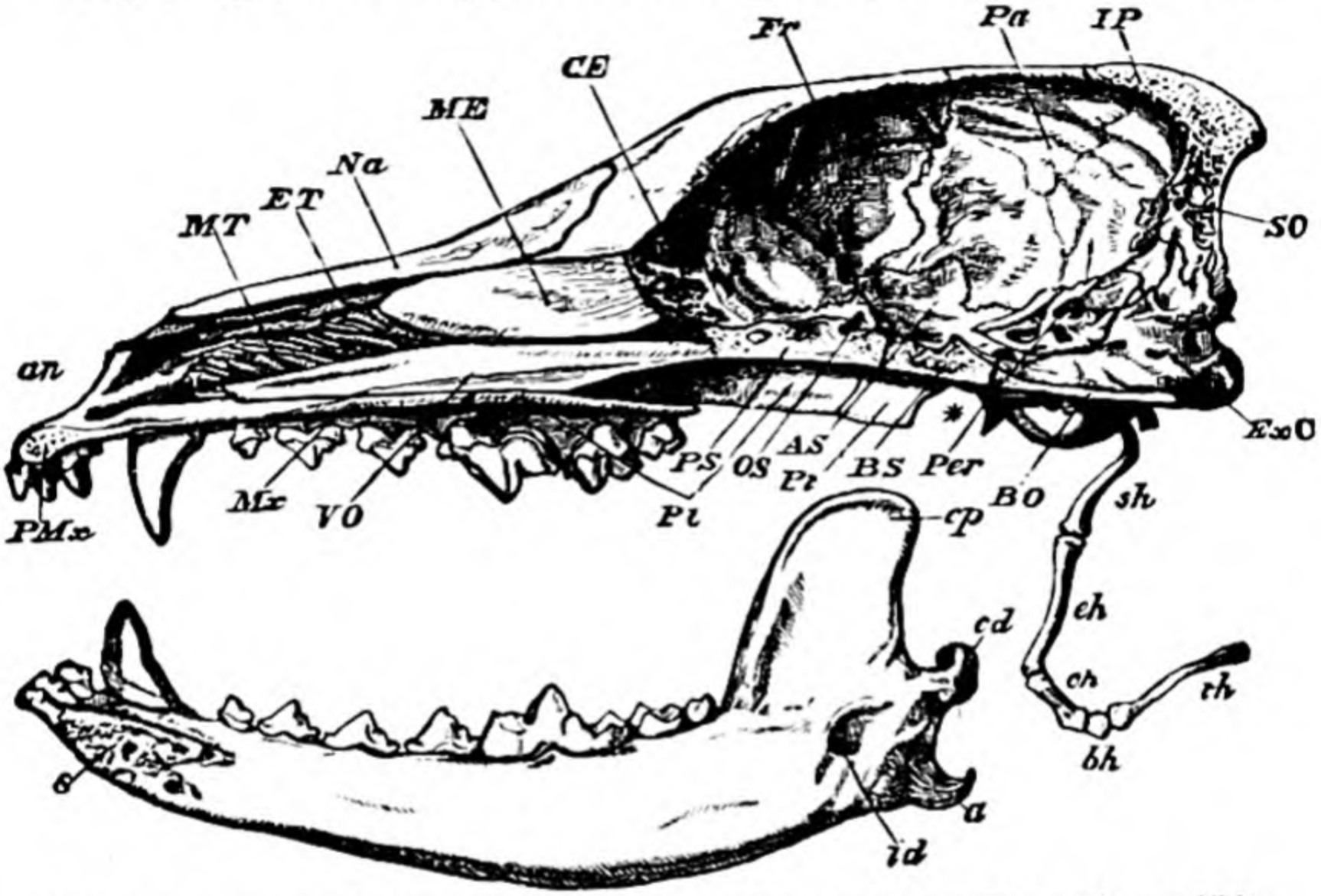


FIG. 220.—Longitudinal and vertical section of the skull of a Dog with mandible and hyoid arch. (× ½.)

an. anterior narial aperture; *MT*. maxillo-turbinal bone; *ET*. ethmo-turbinal; *ME*. mesethmoid; *CE*. cribriform plate of the ethmoid; *Per*. petrous portion of the periotic bone; *os*. orbitosphenoid; *sh*. stylohyal; *eh*. epihyal; *ch*. ceratohyal; *bh*. basihyal; *th*. thyrohyal; *s*. symphysis of mandible; *cp*. coronoid process; *cd*. condyle; *a*. angle; *id*. inferior dental canal. The mandible is displaced downwards to show its entire form; the * indicates the part of the cranium to which the condyle is articulated. (From Flower's *Osteology of the Mammalia*.)

of being retracted into a sheath of skin (as in the cats); or relatively short and blunt, in which case they are incompletely or not at all retractile. The Otter differs from the rest in having short limbs with the toes connected by webs of skin. The Seals and Walruses show greater or lesser adaptation to an aquatic life.

The Dog, *Canis familiaris*, the Wolf, *C. lupus*, the Jackal, *C. aureus*, and the Fox, *C. vulpes*, are all species of the same genus, being distinguished from each other by size and slight peculiarities of hair, etc.; and similarly the Lion, *Felis leo*, the Tiger, *F. tigris*, the Leopard or Panther, *F. pardus*, so closely resemble the common cat, *F. catus*, that they also are regarded as different species of one genus. The differences in the colour of skin which help to distinguish them are in all probability due to the fact that the colours are protective, enabling the animals when in their natural surroundings to come close to their prey without the latter noticing them. Lions live as a rule in dry and rather open places, and are of a dun colour which harmonizes well with the surroundings; the stripes of the tiger's skin deceptively resemble the alternating shadows and sunlit spaces of ground found amongst the reeds in which it lives; the spots of a leopard are unnoticeable amidst the patches of light and shade caused by the sunlight struggling through the interstices between leaves of trees in a forest.

The **Cetacea,** which include the Whales, the largest of existing Mammals, are interesting as showing a complete adaptation to an aquatic mode of life. As is well known, they pass all their life in water and show great differences in structure from all land Mammals in all parts of their body.

The body is fusiform, fish-like, tapering backwards to the tail, provided with a flattened tail-fin, which is expanded in the horizontal plane, not in the vertical plane as in Fishes. Whales progress by moving the tail-fin up and down, whereas the movement in fish is from side to side. A dorsal median fin is usually present. All external trace of hind-limbs has disappeared, though a pair of small bones representing the pelvic girdle are found embedded in the body. The

fore-limbs have become flappers, with the digits devoid of claws and bound together by skin to their very tips. The number of phalanges in each finger (Fig. 222) is greatly increased. The limb is buried in the body almost to the wrist, yet the skeleton clearly shows that it consists of the same bones as in other Mammals, and has no resemblance with that of the Fishes. The mouth is very wide, the nostrils are situated on the summit of the head, and the auditory pinna is absent. Hairs are

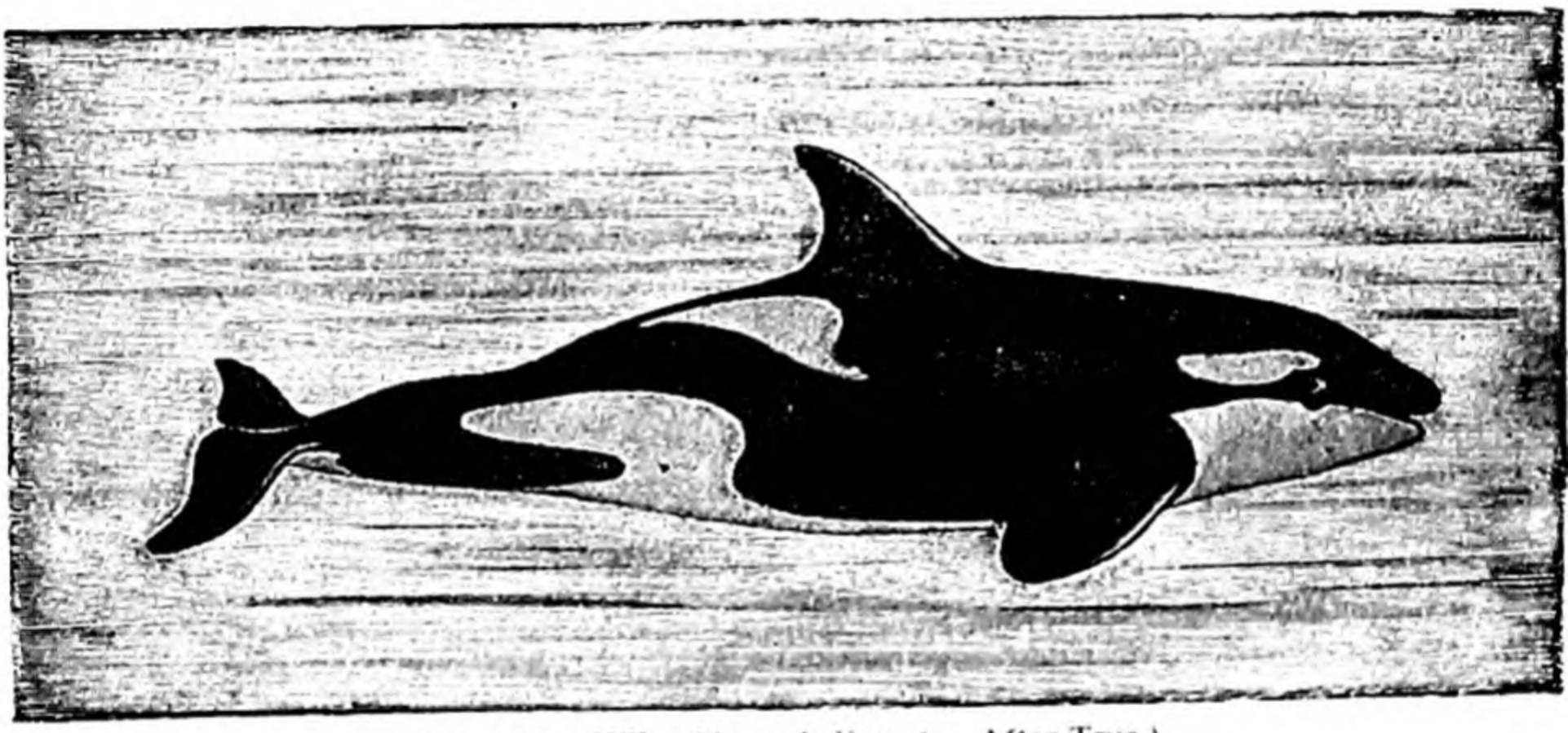


FIG. 221.—Killer (*Orca gladiator.*) After True.)

almost completely absent, only one or two being found in the region of the lips in the embryo only. The body is covered with a thick layer of fat termed blubber, which preserves the heat of the body and protects the animal against the cold of the watery medium.

In the great group of the **Ungulata,** or hoofed animals, all power of grasping with the limbs is absent, and all the four " feet " are purely adapted for running, the " toes " being encased in hard blunt nails which are called hoofs. The thigh and the upper arm are more or less buried in the body, whilst the heel and the wrist are raised in

walking so that the animal goes along on the tips of its toes. The bones of the wrist are arranged in transverse rows, the members of the two adjacent rows alternating with one another. The first digit in both fore- and hind-limbs is always absent. The Ungulates are divided into two great groups—(1) the **Perissodactyla,** in which there is an odd number of toes and in which the true central

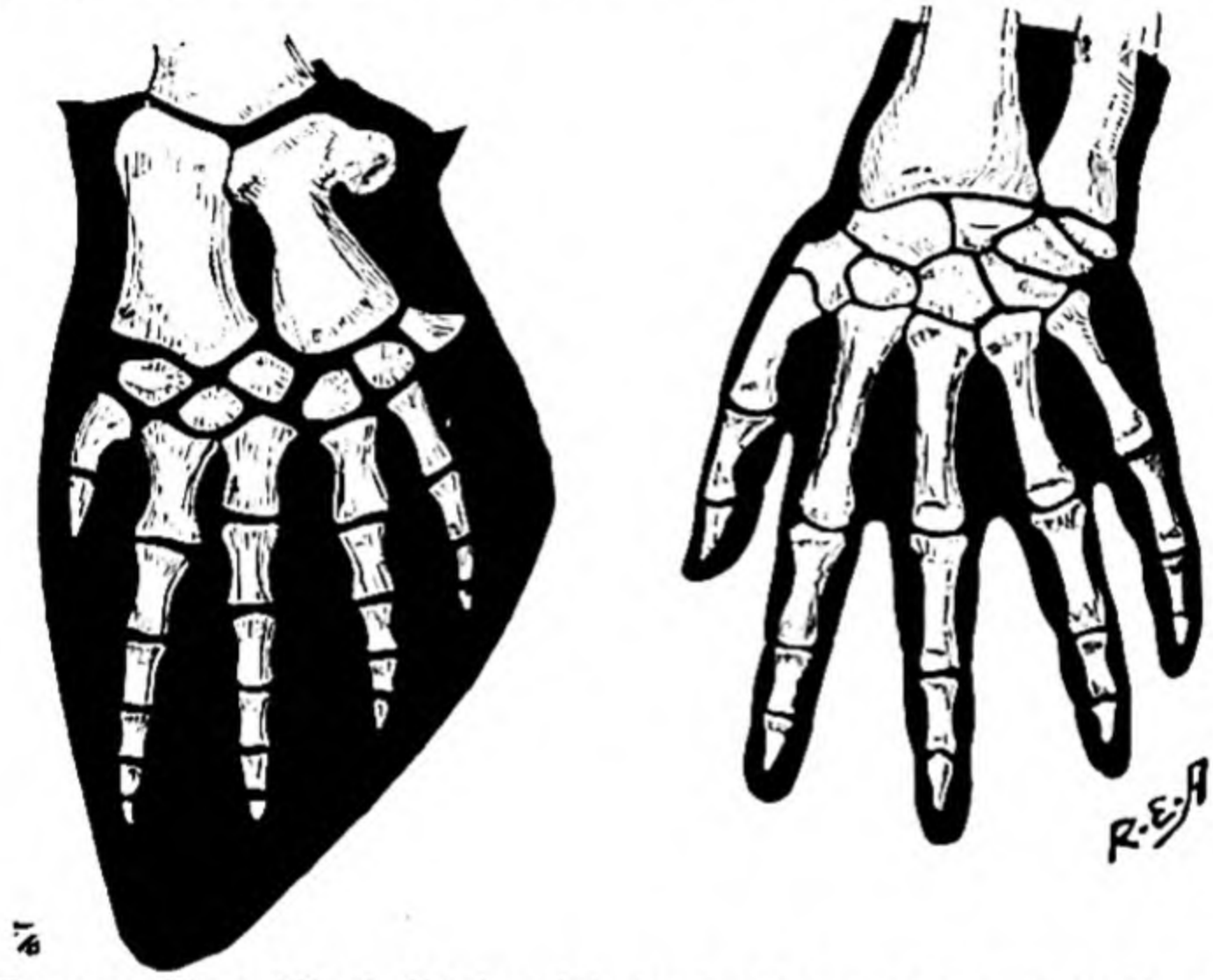


FIG. 222.—The paddle of a Whale and the hand of Man compared. (From Romanes' *Darwin and after Darwin.*)

axis of both arm and leg passes through the centre of the third finger or toe (Fig. 223), and (2) the **Artiodactyla,** or even-toed, in which the third and fourth digits of each foot form a symmetrical pair, and in the majority are the only completely developed digits. (Fig. 224).

In the **Elephants,** the largest of existing terrestrial Mammals, the limbs are much more typically developed than in the true Ungulates. There are five compara-

tively short digits, enclosed in a common integument in each foot, most of which end in broad flat nails. The limbs are very stout and pillar-like, the thighs and upper arms being quite free from the body, and not buried in the general contour of the body, as in most other Mam-

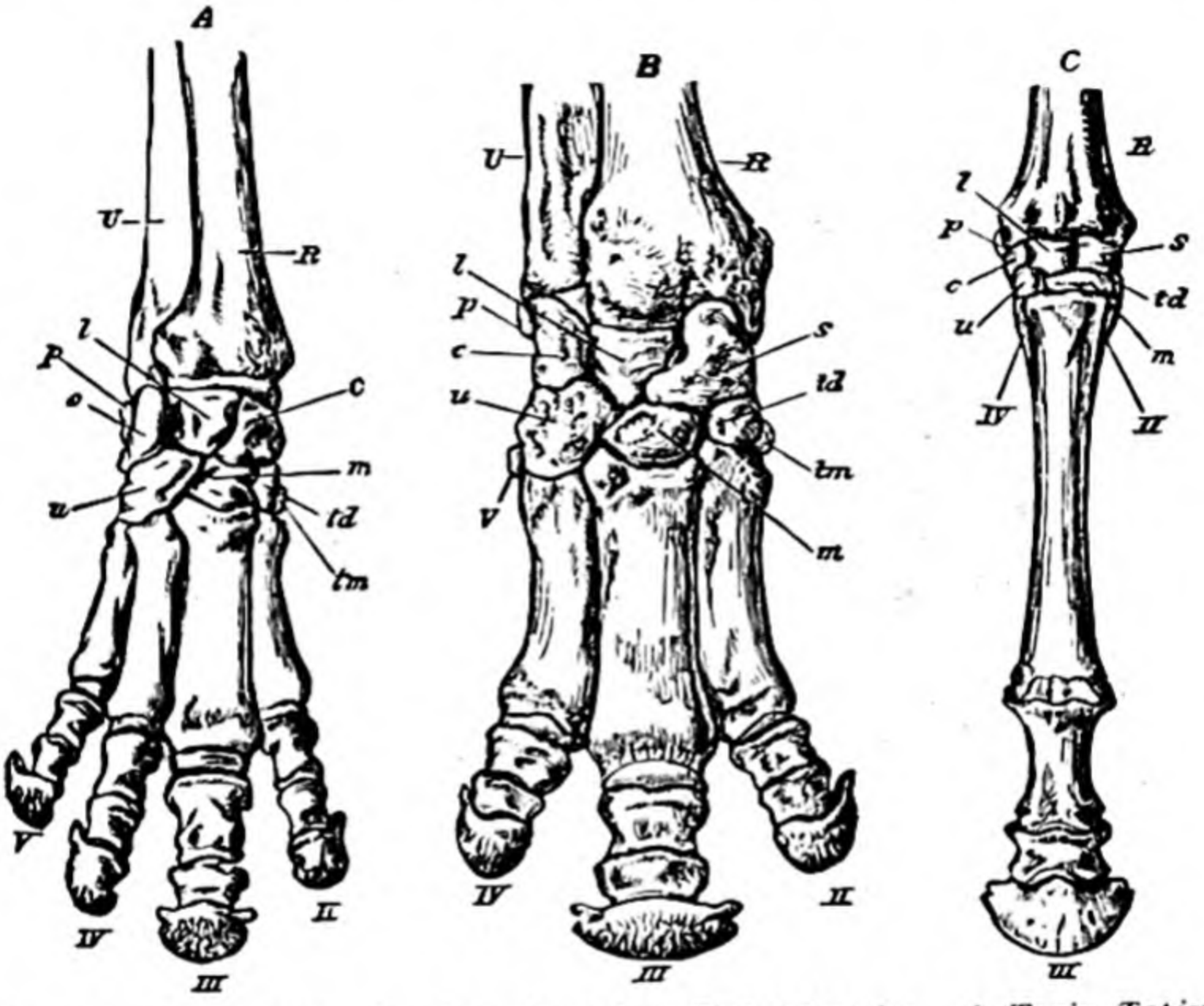


FIG. 223.—Bones of the fore-foot of existing Perissodactyles. *A*, Tapir, *Tapirus indicus*, × ⅛; *B*, Rhinoceros, *Rhinoceros sumatriensis*, × ⅛; *C*, Horse, *Equus caballus*, × ⅛.
R. radius; *U.* ulna; *s.* scaphoid (radiale); *l.* lunar (intermedium); *c.* cuneiform (ulnare); *p.* pisiform; *tm.* trapezium (first distal carpal); *td.* trapezoid (second distal carpal); *m.* magnum (third distal carpal); *u.* unciform, fused fourth and fifth distal carpal. II—V, second to fifth digits. (From Flower's *Osteology of the Mammalia.*)

mals. The trunk, or proboscis, is really a long, flexible snout, at the end of which are situated the nostrils; and in the Indian elephant a finger-like lip is attached to the upper margin of the end of the trunk. The tusks are the incisor teeth of the upper jaw. The canines are

absent. The molars are so large that the jaws cannot at one time accommodate more than at the most two and a part of a third. These molars being the only functional teeth, the elephant is popularly described as having different teeth for mastication and for show.

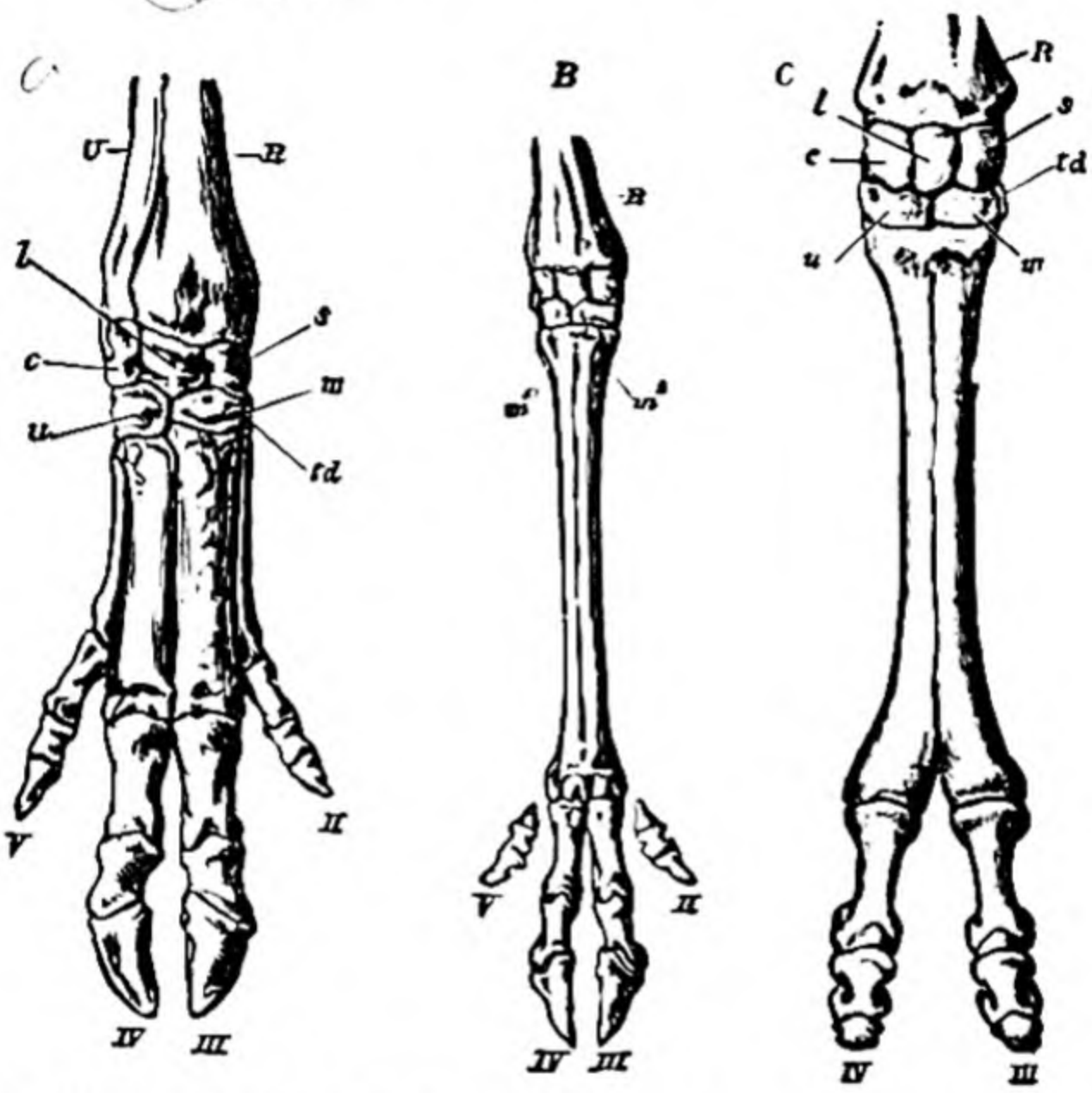


FIG. 224.—Bones of the fore-foot of some Artiodactyla. *A*, Pig, *Sus scrofa*, × ½; *B*, Red deer, *Cervus elaphus*, × ⅛; *C*, Camel, *Camelus bactrianus*, × ½. Letters as in the preceding figure. (From Flower.)

The **Rodentia** or Gnawers (Lat. *rodo*, to gnaw) are all vegetable feeders and are sharply marked off from other mammals by the character of their teeth (which has been fully described in the case of the Rabbit, see p. 467). Their incisors, which are adapted for gnawing, are never more than two in number in the lower jaw and in most of them there are only two in the upper jaw also. There

FIG. 225.—Wing of an extinct flying Reptile, Bat, and Bird compared. (From Romanes' *Darwin and after Darwin.*)

are no canines, so that there is a considerable space or diastema between the front and the back teeth.

The **Chiroptera** (Gk. *cheir*, a hand; *pteron*, wing) or Bats are the only mammals which are capable of active flight, for which purpose their arms are modified into wings. As in birds, the fore-arm is bent up on the upper arm, the wrist bent down on the fore-arm; but, unlike the wing of birds, the flying membrane is of skin and not of feathers. The membrane is stretched chiefly between the fingers of the five-fingered hand, and further extends back to the hind-limbs. Part of the membrane extends down the thighs, and in some even the tail is involved. The hand is enormous, the "little finger" being, as a rule, very greatly elongated, while the thumb alone, is small, is not included in the membrane, and ends in a curved claw.

The **Primates,** as stated above, include Lemurs, Monkeys, and Man. The order is characteristically arboreal—that is to say, most of its members live among trees, climbing from branch to branch. The thigh and the upper arm are quite free from the body, and the whole sole of the foot and palm of the hand are placed on the ground in walking. There are five fingers and five toes, some of which at least have flat nails. The big toe is shorter than the rest, and, except in Man, can be separated from them so as to be used for grasping, in the same way as can the thumb in Man and most Monkeys. Thus at one time in the History of Zoology Monkeys were wrongly regarded as possessing four hands and placed in a separate order (Quadrumana) from that of Man (Bimana). The eyes are placed in the front of the skull instead of at the sides of the head, and the jugal joins the postorbital process of the frontal, so that the orbit is surrounded by a bony ring. There are two large mammæ situated on the breast only (an extra

pair on the abdomen found only in some Lemurs being vestigial).

The order is divided into two sub-orders, the **Lemuroidea,** including the Lemurs, and the **Anthropoidea,** including the true Monkeys and Man. The Anthropoidea are distinguished by the fact that the bony ring surrounding the orbit sends inward a plate which completely separates off the orbit from the temporal fossa. The cerebral hemispheres conceal the cerebellum when the

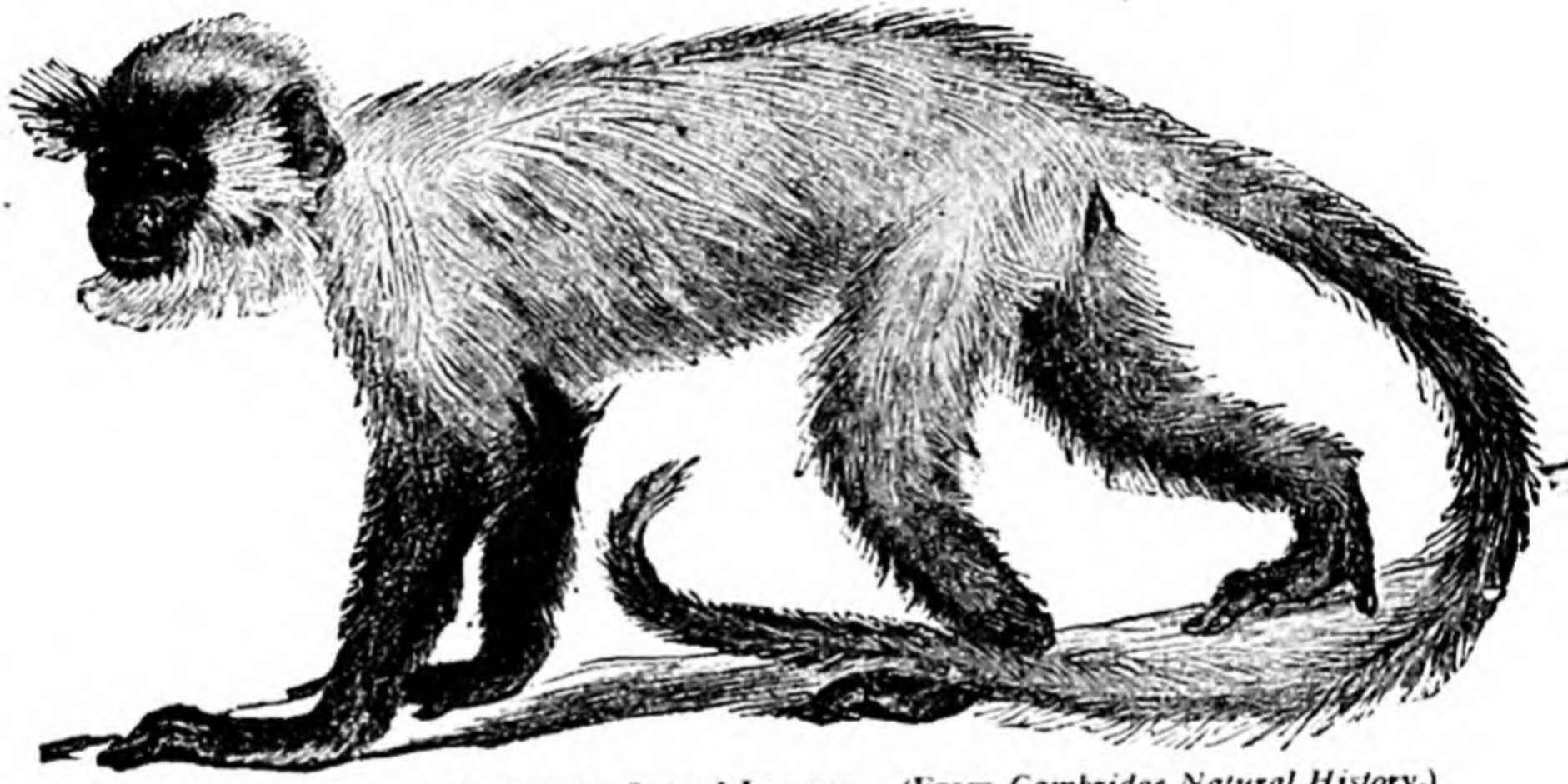


FIG. 226.—*Semnopithecus*, the Sacred Langur. (From *Cambridge Natural History*.)

brain is viewed from above. The placenta is at first spread all over the surface of the embryo, but later becomes concentrated on one part of the wall of the uterus (metadiscoidal placenta), and is deciduate (see p. 581). There are never more than two mammæ. Leaving aside the Marmosets and the Howling and the Spider Monkeys of America, we come to the old world Monkeys which belong to the families *Cercopithecidæ* and *Simiidæ*. The former include the Macaques, the Baboons, and the Sacred Langur (*Semnopithecus*) of

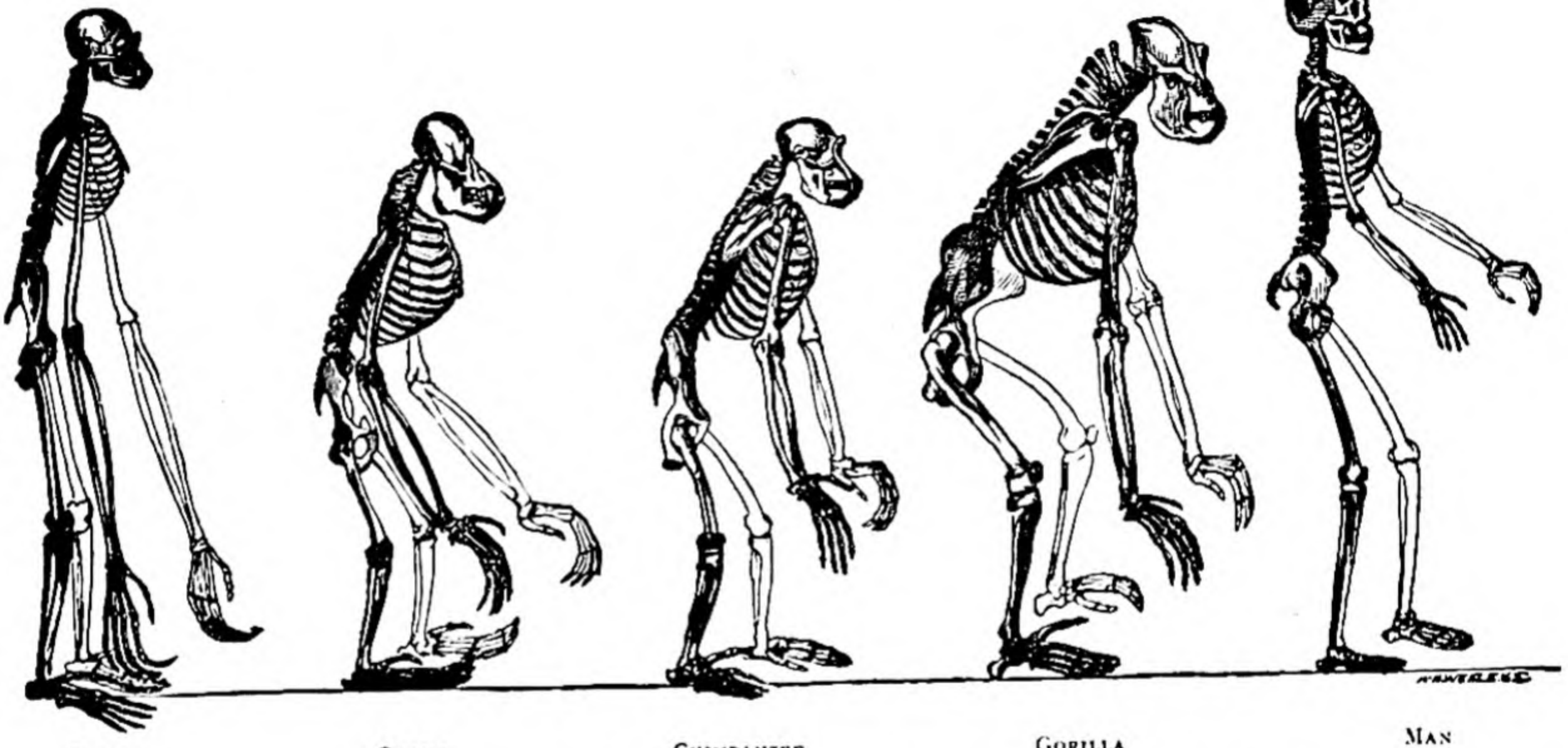


FIG. 227.—Skeletons of the Anthropoid Apes and Man. (From Huxley's *Man's Place in Nature*.)

[Photographically reduced from diagrams of the natural size (except that of Gibbon, which was twice the natural size).]

India. They have their legs as long as their arms, or longer, and go habitually on all fours. There are always brightly coloured bare patches of skin (callosities) over the ischia, on which the animals rest when they assume a sitting posture, and there is in almost every case a well-developed tail. In the Simiidæ or Man-like Apes the tail is completely absent. There are four genera known, *Hylobates* (Gibbons), *Simia* (Orang-utan), *Gorilla* (Gorilla), and *Anthropopithecus* (Chimpanzee). In all these (Fig. 227) the arms are longer than the legs, and they walk in a semi-erect manner. The Gibbons can walk in an upright manner holding out their long arms as if they were balancing poles; in the others, though in walking on the ground the body may be held in a semi-erect position with the weight resting on the hind-limbs, the long fore-limbs reach the ground and are used as crutches.

Man (*Homo sapiens*) is distinguished above all by the great size of the brain, which is about double the size of that of the highest monkey, and by the modification of the hind-limbs to support the body and enabling him to walk erect. The great toe is no longer used for grasping. The hands being thus entirely set free were used to acquire a variety of experiences, and the intelligence of man awakened. Another great factor which must undoubtedly have stimulated the mental development of Man is his habit of living together in societies and undertaking concerted action for the good of the community. To this power of combination may be traced the evolution of language and morals. "Man did not make society, it was society that made Man."

Early Development of other Types.—The presence of a greater amount of food-material in the egg renders it possible for the embryo to go on developing further than the gastrula-stage before being hatched, and, as a general rule, the greater the relative quantity of yolk present in the ovum of an animal, the less clearly can a gastrula-stage be recognized.

In the **earthworm** and **mussel** the segmentation is entire, but unequal, and the larger lower cells become invaginated to form the endoderm and enteron while the smaller upper cells give rise to the ectoderm. In the earthworm the blastopore does not become closed, but gives rise to the mouth.

In the **frog** (p. 180) the enteron arises by a split appearing amongst the yolk-cells, beginning at the edge of the blastopore and gradually extending inwards: the process is supplemented by an invagination of the ectoderm. The enteron is at first a very narrow cleft, but soon widens considerably (Fig. 66, I, *ent*): for some time it does not actually communicate with the exterior, the blastopore (*blp*) being filled up by a yolk-plug (*yk. pl*). As the enteron extends forwards, and the relatively small segmentation-cavity (*bl. cœl*) gradually disappears, the edges of the lower margin of the blastopore approach one another and, uniting in the median plane, give rise to a vertical band at the hinder end of the embryo, in which the three germinal layers are fused together. This band is spoken of as the *primitive streak*, and the faint median groove which runs along it and marks the line of union of the right and left lips of the blastopore is called the primitive groove. There is no stage in the frog which exactly corresponds with the gastrula-stage in Amphioxus, but the stage represented in Fig. 66, I, most nearly approaches to it.

In the centrolecithal egg of the **crayfish** a gastrula-

stage is formed by invagination, but as the centre of the oosperm is filled with solid yolk in the place of a segmentation-cavity containing fluid, the invagination only extends a short distance inwards, the enteron being relatively very small and the ectoderm separated from the endoderm by the yolk.

The gastrula-stage is much less clearly distinguishable in the segmenting telolecithal eggs of the **dogfish** and **bird** (p. 543), in which the relatively enormous mass of unsegmented yolk is, as in the arthropods, sufficient to nourish the embryo until it has reached a stage closely resembling the adult in almost every essential respect except size. A blastopore can sometimes be recognised in such cases, but in the embryo of the common fowl it is to some extent represented by a *primitive streak* and *groove* (see p. 551 and Fig. 236, E, *pr. st*). The blastoderm becomes differentiated into an outer ectoderm and an inner, lower layer of cells (compare Fig. 236, F), between which and the yolk the enteric cavity is formed: a segmentation-cavity is recognisable in early stages. As the embryo develops, it becomes folded off from the yolk, which is gradually reduced in amount and in later stages is contained in an extra-embryonic part of the embryo—the *yolk-sac* (Fig. 236).

A more detailed account of the early stages of the chick is given below, as the hen's egg is an easily procurable type for the practical study of development.

The hen's egg has already been described in detail (p. 534, Fig. 231). Its essential part, the yolk, corresponds, as we have seen, to a single cell enormously enlarged by the mass of yolk-granules it contains, the only part in which they are absent being a small area which, owing to its lesser specific gravity, is always found at the upper pole; this area, in which the nucleus lies, is known as the *germinal disc*. Fertilization takes place in the anterior end of the oviduct, and then the nucleus divides and initiates the process of seg-

mentation which is completed by the time the egg is laid, when the germinal disc has thus become converted into a multicellular *blastoderm* (p. 534).

The first stage of segmentation is indicated by the formation of a vertical furrow across the centre of the germinal disc (Fig. 236, A), and this is followed by another furrow at right angles to it (B). Further radial and concentric furrows then arise (C) until the blastoderm is seen to consist of a number of irregular cells (D). Horizontal furrows are in the meantime formed, so that the originally single layered blastoderm, beneath which a narrow space representing the *segmentation-cavity* can be recognised, comes to consist of several layers of cells, the outer of which corresponds to the *ectoderm*; the inner, or lower layer cells, extend rapidly through the segmentation-cavity between the ectoderm and the yolk and give rise to the *endoderm*, the space remaining beneath this layer and the yolk forming the rudiment of the *enteron* (F). New cells are gradually formed round the edge of the blastoderm, which, when the egg is laid, forms a circular patch, about 3·5 mm. in diameter, on the surface of the yolk (Fig. 231): its central part, or *area pellucida*, owing to the presence of fluid in the underlying space, is more transparent than the rim, or *area opaca*.

When the egg is incubated, the blastoderm grows rapidly at its periphery (area opaca), and eventually, as we shall see, encloses the whole yolk. The area pellucida extends less rapidly and becomes pear-shaped in outline (Fig. 236, E), its broader end corresponding to what will become the anterior end of the embryo: in this region most of the lower layer cells are arranged so as to form a definite layer of endoderm, which can be recognised somewhat later in the area opaca also. The ectoderm and lower layer cells are at first continuous round the edge of the blastoderm, but later on this is only the case at the posterior border (F), and results in the appearance of a narrow band, the *primitive streak* (E, *pr. st.*), along which a median *primitive groove* is formed. This, as already mentioned, represents the fused lips of the blastopore of the frog and other forms; it extends from the centre to the posterior border of the area pellucida, and rapidly grows backwards. The primitive streak is due to the multiplication of ectoderm cells, which grow inwards and spread out right and left under the covering ectoderm, between it and the endoderm, so as to form a horizontal wing of cells on either side (G). The *mesoderm* is formed from these wing-like ectodermic sheets, with which the endoderm becomes united, so that the three layers are for a time

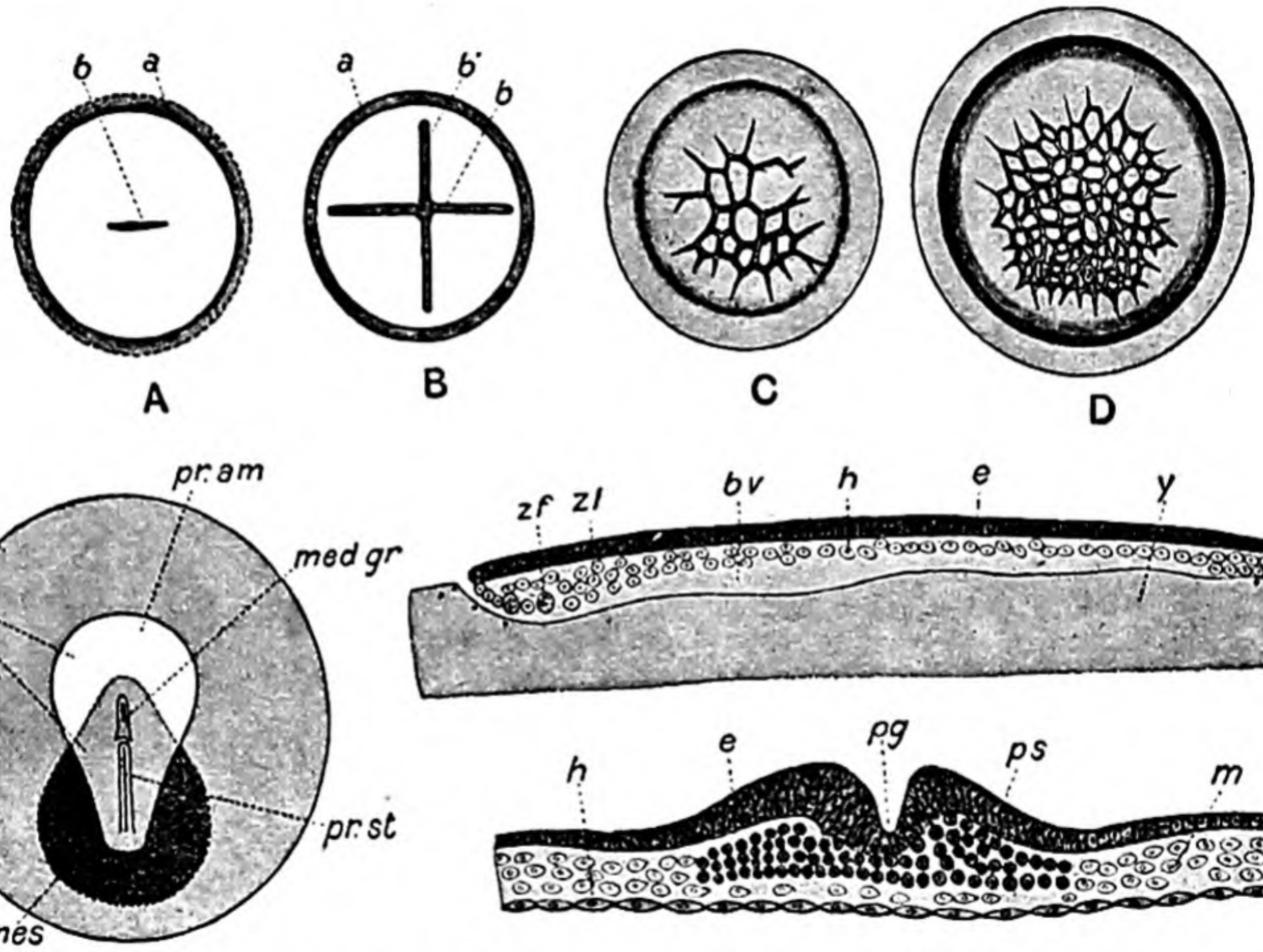


FIG. 236.—Early stages in the development of the blastoderm in a Hen's egg.
A, germinal disc, showing first segmentation furrow; *B*, second furrow; *C*, later stage with numerous blastomeres; *D*, stage towards completion of segmentation (*A*—*D* × 7½); *E*, Diagram of blastoderm at about the twentieth hour of incubation (× 6);

F, vertical section of blastoderm and adjacent part of the egg at the time of laying, before incubation: the anterior edge of the blastoderm is to the right, the posterior edge to the left of the figure (× 25); *G*, transverse section of blastoderm at about the twentieth hour of incubation, the section passing through the primitive streak and groove at about the middle of its length (× 200).

a. periphery of germinal disc; *ar. op*. area opaca; *ar. pl*. area pellucida; *b*. first, and *b'*. second furrow; *bv*. rudiment of enteron; *e*. ectoderm; *h*. endoderm; *n'*. nucleus in yolk around which a cell will be formed later; *m*. *mes*. mesoderm; *med. gr*. medullary groove; *pg*. primitive groove; *pr.am* pro-amnion; *pr. st*. primitive streak; *y*. yolk; *zf*. formative cell; *zl*. lower layer cells. (*A* and *B*, from Foster and Balfour; *C*—*G*, from Marshall, after Duval and Coste.)

indistinguishable in this region. The mesoderm eventually forms a sheet of loosely arranged cells which spreads rapidly in all directions except anteriorly (E), in which region, known as the *pro-amnion*, the blastoderm consists of ectoderm and endoderm only until the end of the second day of incubation, and by the third day the three germinal layers have become established in the whole of the blastoderm.

Before tracing the development of the various organs derived from the three germinal layers respectively, it must be remembered that the actual chick embryo is formed from the area pellucida, and gradually becomes folded off from the yolk, while the area opaca extends over the yolk until the latter is entirely covered by it (17th day of incubation): thus we can distinguish between an *embryonic* and an *extra-embryonic* portion of the blastoderm. In the mesoderm of the latter portion blood-vessels are formed, so that it is then known as the *area vasculosa* (see Fig. 236, E).

The minute egg of the **rabbit** (compare p. 505) and of most other mammals, although microlecithal and undergoing a holoblastic segmentation, has presumably been derived from a meroblastic type with abundant yolk, like that of the reptiles and birds, and some lower mammals (*Ornithorhynchus* and *Echidna*) living in Australia at the present day still possess eggs of this type. In the higher Mammalia the yolk has disappeared, as it is no longer needed, the embryo, as we have seen (p. 505), being nourished by means of a *placenta*, which will be described presently. The early processes of development are therefore somewhat peculiar, and though the segmentation is holoblastic, the subsequent development is for some time essentially similar to that of the bird:

it is not until later stages that the more special characteristics of the mammal on the one hand and the bird on the other become apparent.

Fertilization and segmentation take place in the uterine tubes (p. 504), and each oosperm is surrounded by a membrane, the *zona radiata*, apparently formed from the follicle cells, and a layer of albumen secreted from the oviduct. The oosperm divides into two blastomeres (Fig. 237, A), and then further divisions follow and result in the formation of a mulberry-like mass (B), which, however, is not hollow, as in Amphioxus (Fig. 235), but consists of an outer layer enclosing a solid mass of larger and more granular cells (C), and at this stage it passes into the uterus. The outer layer of cells then grows rapidly, so that a space appears and gradually increases in size, between it and the inner mass except at one point where the latter is attached to the former (D, E). This hollow ball is known as the *blastocyst* or *blastodermic vesicle*, and may be compared to the embryo and yolk-sac of a bird, except that it contains a fluid instead of yolk. The outer layer probably corresponds to the extra-embryonic ectoderm of the chick (p. 553) and takes no direct part in the formation of the embryo, which arises from the inner mass (*embryonic area*), in much the same way as the chick is formed from the blastoderm in the case of the hen's egg. Thus later on an embryonic portion, with a primitive streak, and an extra-embryonic portion gradually growing round beneath the outer layer, can be recognised in the embryonic area, the body of the embryo being gradually folded off from the blastocyst, which has similar relations to the embryo as the yolk-sac has to the body of the chick, to which it corresponds (see p. 550 and Figs. 236 and 242).

In Amphioxus alone amongst the triploblastic animals described in this book does the mesoderm arise as a series of enterocœlic pouches: as we have seen, it is usually at first solid, and may be budded off from the ectoderm and endoderm, or from the ectoderm only, at the margin of the blastopore or primitive groove (chick, p. 551); or both endoderm and mesoderm may be differentiated at the same time from the lower-layer cells or yolk-cells (frog, p. 181); or finally, it may arise

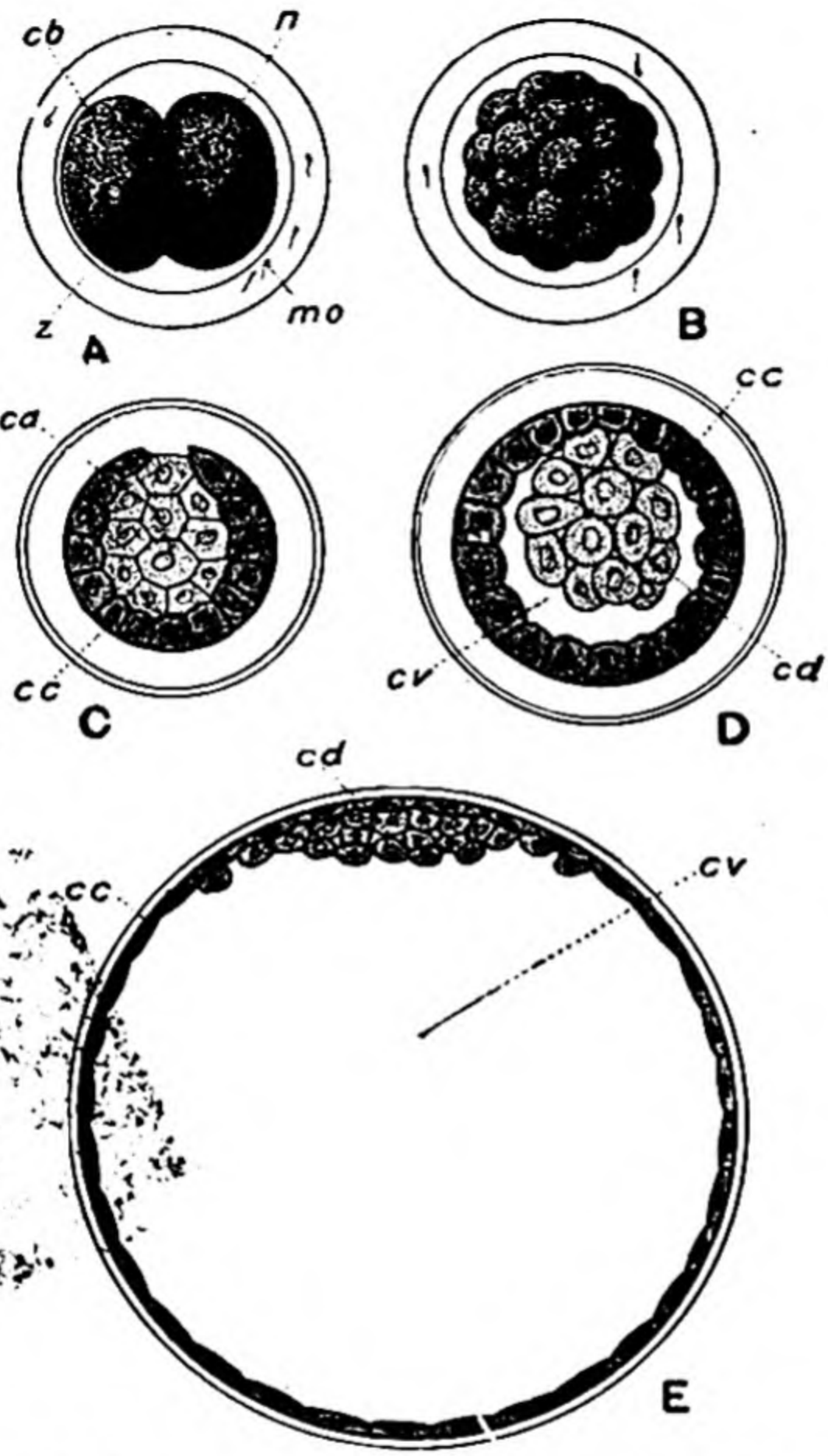


FIG. 237.—Early stages in the development of the oosperm of the Rabbit.

A, two-celled stage, from middle part of the uterine tube, about twenty-two hours after copulation; *B*, polyplast or morula stage, from lower end of uterine tube, about the middle of the third day; *C*, close of segmentation, from lower end of uterine tube just before entering uterus, seventy hours after copulation; *D*, first stage in formation of blastocyst, from uterus, seventy-five hours after copulation; *E*, section of blastocyst at the end of fourth day. (× about 160.)

cb. blastomere; *cc*. outer layer of cells; *cd*. inner mass of cells (embryonic area); *cv*. cavity of blastocyst; *mo*. sperms imbedded in the zona radiata (*z*); *n*. nucleus. (From Marshall; *A*, *B*, after Bischoff; *C*—*E* after Van Beneden.)

in all these ways. The cœlome is formed secondarily by a split taking place in the mesoderm on either side (Figs. 248 and 250), the split gradually extending with the extension of the mesoderm between the ectoderm and endoderm. Thus the cœlome is formed, not as an enterocœle, but as a *schizocœle*.

In Vertebrates each mesoderm-band becomes differentiated into a dorsal portion abutting against the medullary cord and notochord known as the *vertebral plate*—which soon loses its cœlomic space, and a ventral portion, the *lateral plate*, which is divided into parietal and visceral layers by the cœlome (Figs. 67 and 250 B, C). The vertebral plate undergoes metameric segmentation, becoming divided into a row of squarish masses, the *mesodermal segments* or "*protovertebræ*" (*pr. v, ms. s*), from the outer parts of which (*muscle-plates*, the muscular segments or myomeres are formed (p. 411), and from the inner parts the vertebral column, the segmentation of which alternates with that of the myomeres.

Outline of the Development of the Chief Organs in the Vertebrata (compare pp. 180–186).—The **nervous system** as well as the essential parts of the **sensory organs,** are, as we have seen, in all cases formed from the ectoderm. The development of the central nervous system takes place in essentially the same manner as in the frog (p. 182).

In the chick the ectoderm in front of the primitive streak early becomes thickened along the median line to form the *medullary plate* (Fig. 236, E); this gradually increases in length at the expense of the primitive streak, from the cells of which the greater part of the embryo is eventually developed. A *medullary groove*, bounded by *medullary folds* (Fig, 238, A and B), is formed along the median line of the medullary plate and passes into the primitive groove posteriorly; while near their anterior ends the folds meet and unite, so as to constrict off a *medullary tube* from the

outer ectoderm (Figs. 236, E and 238, A). This closure of the tube then gradually extends both forwards and backwards, the groove remaining open longest at its posterior end. In the region of the pro-amnion (p. 553, Figs. 236, E, and 238, A) a transverse crescentric fold of both ectoderm and endoderm, extending across the area pellucida a short

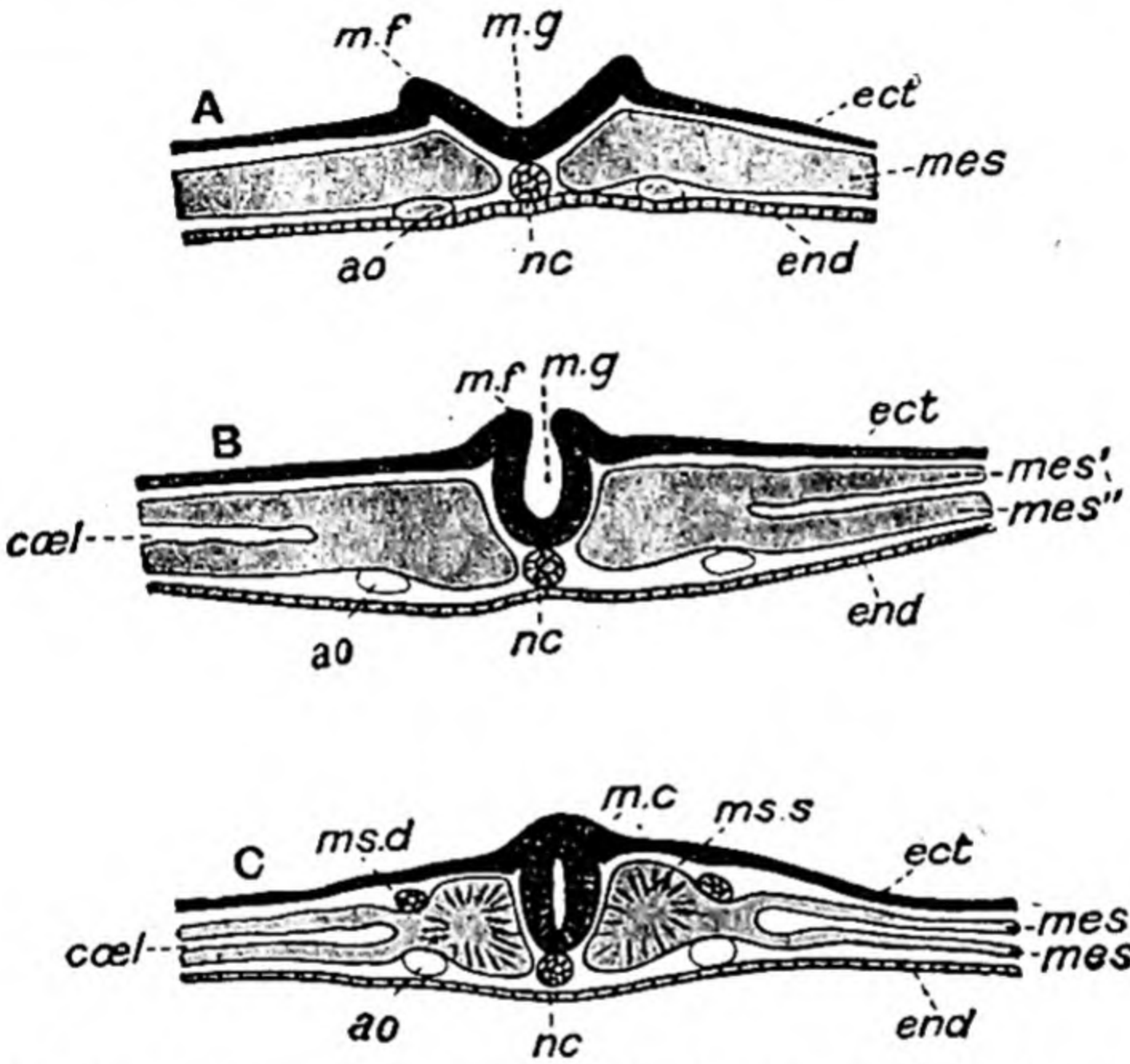


FIG. 238.—Transverse sections across the body of a chick embryo at the twenty-fourth to thirtieth hour of incubation, to show stages in the formation of the medullary cord and cœlome. (× 100.)

ao. aorta; *mes.* mesoderm; *mes'.* parietal, and *mes''.* visceral layer of mesoderm; *m. f.* medullary fold; *m. g.* medullary groove; *ms. d.* mesonephric duct; *ms. s.* mesodermal segment; *nc.* notochord.

distance in front of the anterior end of the embryo (*head-process*), is formed as the *head-fold* and marks off the anterior end of the embryo from the rest of the blastoderm.

In Vertebrates the anterior end of the hollow medullary tube becomes dilated, forming three bulb-like

swellings—the fore-brain (Fig. 239, A, *f. b*), mid-brain (*m. b*), and hind-brain (*h. b*). Soon another hollow swelling grows forwards from the first vesicle (B, *prs. en*), and the third gives off a similar hollow outgrowth (*cblm*) from its dorsal surface. The brain now consists of five divisions: the *prosencephalon* (*prs. en*) and *diencephalon* (*dien*) derived from the fore-brain, with the pineal structures (*pn. b*, *pn. e*) and the infundibulum, to which the pituitary body becomes attached (*inf*, *pty*); the *mid-brain* or *mesencephalon* (*m.b*), which gives rise to the *optic lobes* and *crura cerebri*; and the *epencephalon* or *cerebellum* (*cblm*) and *metencephalon* or *medulla oblongata* (*med. obl*) derived from the hind-brain. The original cavity of the brain becomes correspondingly divided into a series of chambers or *ventricles* (compare Figs. 52 and 239), all communicating with one another, and called respectively the *fore-ventricle* or *prosocœle*, *third ventricle* or *diacœle*, *mid-ventricle* or *mesocœle* (*iter*, and *optic ventricles* or *optocœles*), *cerebellar ventricle* or *epicœle*, and *fourth ventricle* or *metacœle*.

In some fishes (*e.g.*, dogfish) the brain consists throughout life of these five divisions, but in most cases (Figs. 51 and 207) the prosencephalon grows out into paired lobes, the right and left *cerebral hemispheres* or *parencephala* (Figs. 239, I–L, *c. h*), each containing a cavity, the *lateral ventricle* or *paracœle* (*pa. cœ*) which communicates with the diacœle (*di. cœ*) by a narrow passage, the *foramen of Monro* (*f. m*). From the prosencephalon or the hemispheres are given off a pair of anterior prolongations, the *olfactory lobes* or *rhinencephala* (*olf. l*), each containing an *olfactory ventricle* or *rhinocœle* (*rh. cœ*).

In the preceding description the brain has been described as if its parts were in one horizontal plane; but, as a matter of fact, at a very early period of development the anterior

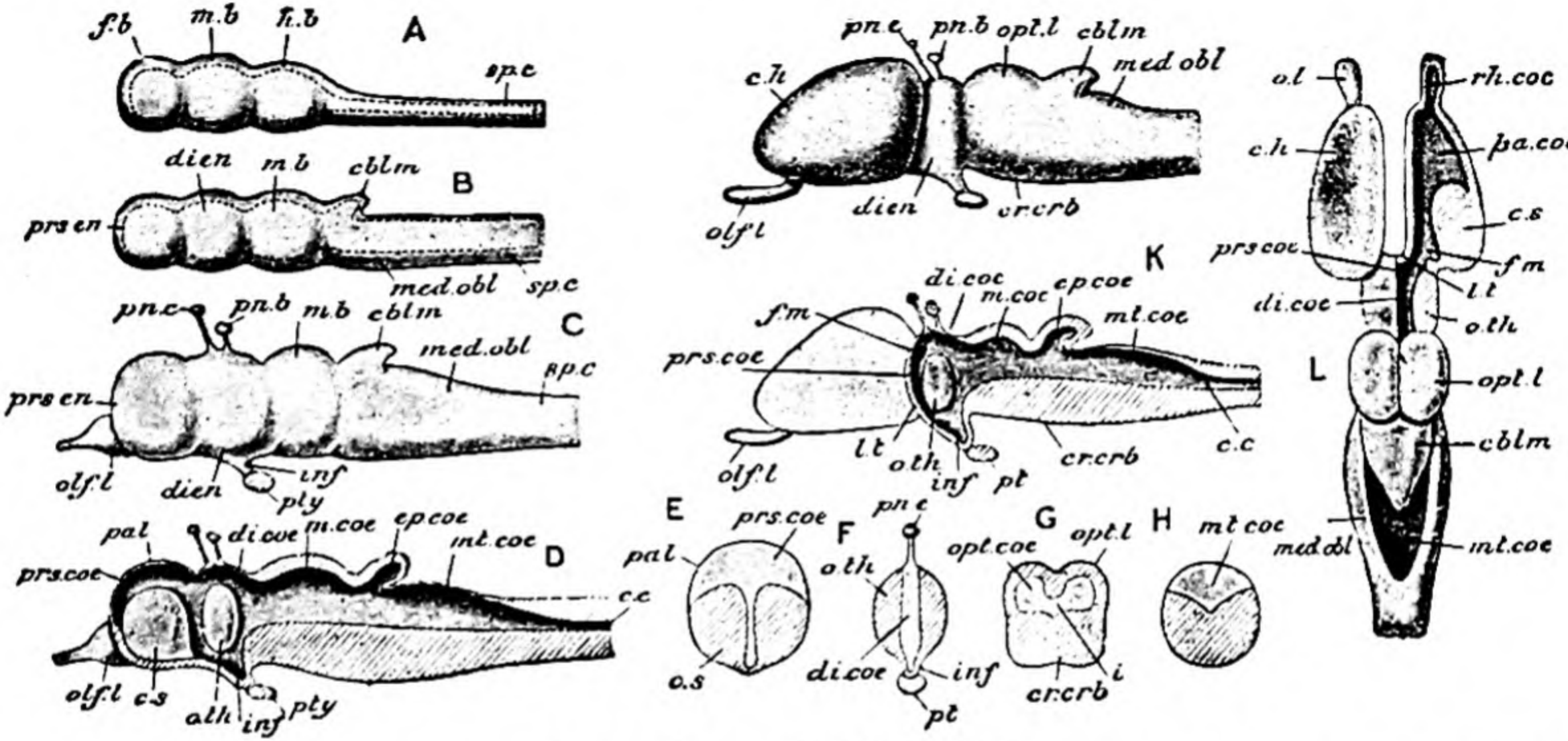


FIG. 239.—Diagrams of the Craniate Brain.

A, First stage, side view, the cavity indicated by a dotted line; *B*, second stage; *C*, side view of fully-formed brain with undivided prosencephalon; *D*, the same in sagittal section; *E*, transverse section of prosencephalon; *F*, of diencephalon; *G*, of mesencephalon; *H*, of metencephalon; *I*, side view of brain with cerebral hemispheres; *K*, sagittal section of the same; *L*, dorsal view, the cavities exposed on the right side.

cblm. cerebellum; *c. c.* central canal; *cr. crb.* crura cerebri; *c. h.* cerebral hemispheres; *c. s.* corpora striata; *di.cœ.* diacœle or third ventricle; *dien.* diencephalon; *ep.cœ.* epicœle; *f.b.* fore-brain; *f. m.* foramen of Monro; *h.b* hind-brain; *inf.* infundibulum; *i.* iter; *l. t.* lamina terminalis; *m.b.* mid-brain; *m.cœ.* mesocœle; *med. obl.* medulla oblongata; *mt.cœ.* metacœle or fourth ventricle; *olf. l.* olfactory lobes; *opt.cœ.* optocœles; *opt. l.* optic lobes; *o. th.* optic thalami; *pa.cœ.* paracœles or lateral ventricles; *pal.* pallium, or roof of prosencephalon; *pn. b.* pineal body; *pn. e.* pineal or parietal eye (compare p. 141); *prs.cœ.* prosocœle; *prs.en.* prosencephalon; *pt. pty.* pituitary body; *rh.cœ.* rhinocœles or olfactory ventricles; *sp. c.* spinal cord. (From Parker and Haswell's *Zoology*.)

part becomes bent down over the end of the notochord so that the whole organ assumes a retort-shape, the axis of the fore-brain being strongly inclined to that of the hind-brain. The bend is known as the *cerebral flexure* (Fig. 241, B): it is really permanent, but as the hemispheres grow forwards parallel to the hind-brain, and the floor of the mid-brain and hind-brain thickens, it becomes obscure and is not noticeable in the adult.

The central cavity of the embryonic spinal cord has at first the form of a narrow vertical slit (Fig. 238, *c*), the walls of which eventually fuse dorsally, while ventrally part of the slit forms the central canal of the adult spinal cord. The lateral walls continue to thicken and finally the cord becomes approximately circular in section and the dorsal and ventral fissures are developed.

The ganglia of the dorsal roots of the *spinal nerves* are developed from a paired *neural crest* (Fig. 247, *n. cr*) arising close to the junction of the medullary plate and outer ectoderm: this becomes segmented to form the ganglia, from the cells of which the sensory fibres arise and extend into the spinal cord. The ventral roots arise as direct outgrowths from cells in the ventral region of the medullary cord. Certain of the *cerebral nerves* are developed in an essentially similar manner to the dorsal roots of the spinal nerves, while others arise as direct ventral outgrowths from the brain, like the ventral roots. The fibres of all the typical nerves grow peripherally until they reach the parts which they ultimately supply.

The *olfactory organs* arise as sac-like invaginations of the ectoderm, one on either side of the snout (Fig. 239), and become enclosed by the cartilaginous olfactory capsules, developed, with the rest of the skeleton, from the mesoderm. The aperture of invagination gives rise to the external nostril, the internal

nostrils (in air-breathing forms) being developed subsequently.

The mode of development of the paired *eye* of vertebrates is peculiar and characteristic.

At an early stage of development a hollow outgrowth —the *optic vesicle* (Fig. 240, A, *op. v*)—is given off from either side of the fore-brain and extends towards the side of the head, where it meets with an in-pushing of the ectoderm (*l*), which becomes thickened, and finally, separating from the ectoderm, forms a closed, spherical sac (B, *l*) with a very small cavity and thick walls (compare Figs. 66, L, *e*, and 240). This body is the rudiment of the lens: as it enlarges it pushes against the optic vesicle, which becomes invaginated, the single-layered optic vesicle, thus being converted into a two-layered *optic cup* (Fig. 240, B, *oc'*, *oc''*), its cavity, originally continuous with the diacœle, becoming obliterated. Between the edge of the cup and the lens, on the ventral side, is a small space which gradually extends towards the stalk of the cup, and thus gives rise to a slit in the wall of the latter: this *choroid fissure* C, *aus*), as it is called, soon becomes closed by the union of its edges. The outer layer of the optic cup gives rise to the pigment-layer of the retina (p. 167): from its inner layer the rest of the retina—including the rods and cones—is formed. The stalk of the optic cup occupies, in the embryonic eye, the place of the optic nerve, but the actual fibres of the nerve are formed from the nerve-cells of the retina and grow inwards to the brain.

During the formation of the lens, mesoderm extends in between the ingrowth from which it arises and the external ectoderm; from this the main substance of the cornea and its inner or posterior epithelium are formed, the adjacent ectoderm becoming the external epithelium,

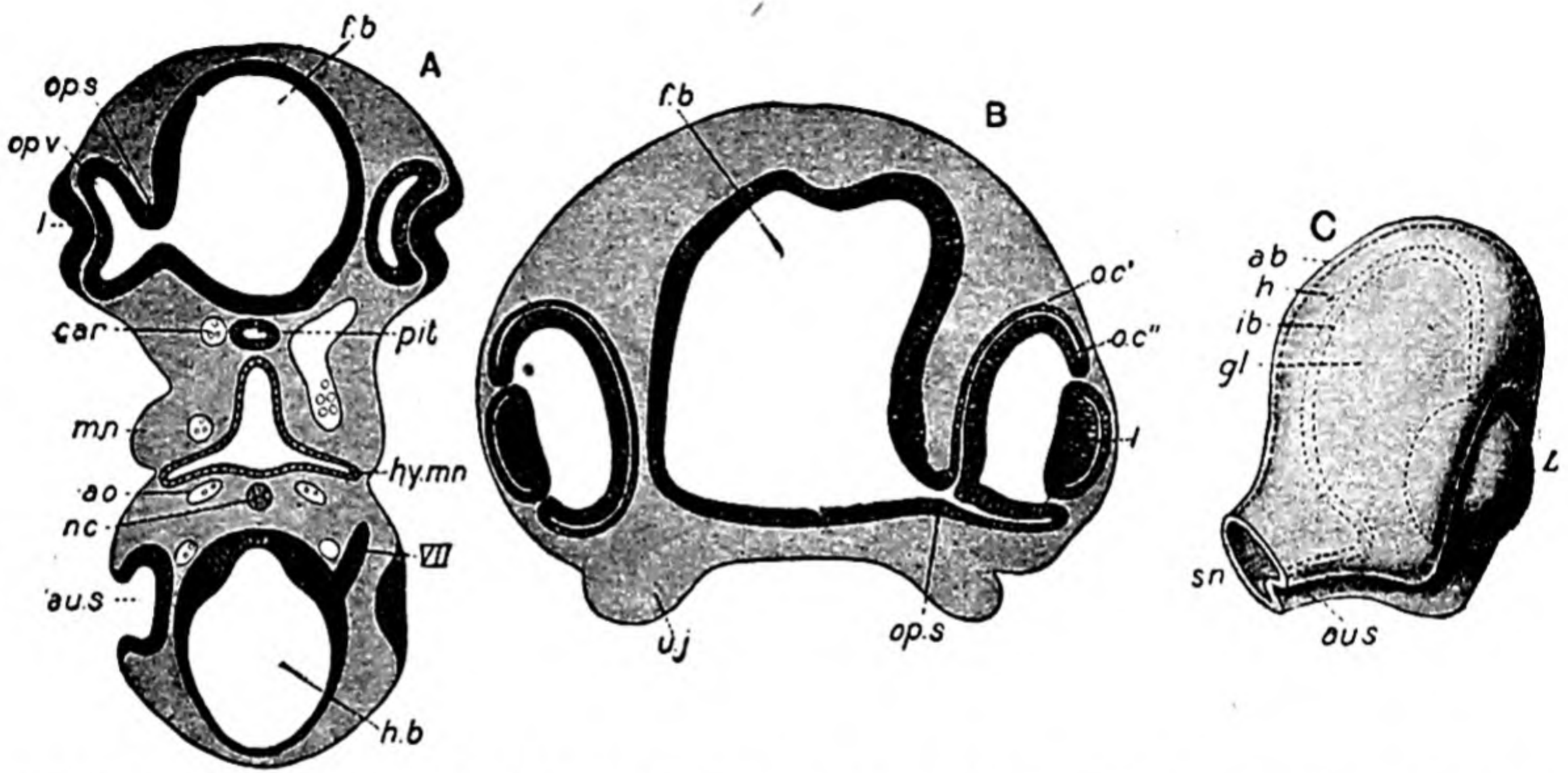


FIG. 240.—*A*, Transverse section across the head of a Chick embryo at the forty-eighth hour of incubation; the section is taken along a line corresponding to one joining the reference letters *au. s.* and *l.* in the three-day embryo shown in Fig. 241, *B*; owing to the cerebral flexure, both fore-brain and hind-brain are cut by the section; the right side of the section is slightly anterior in position to the left side (× 45); *B*, transverse section across the fore-brain and eye of a chick embryo at the sixtieth hour of incubation; on the right side the section passes through the optic stalk, and on the left side just behind the stalk (× 35); *C*, plastic representation of the optic cup and lens. (*A* and *B*, after Marshall; *C*, after Hertwig.)

A and *B*—*ao.* aorta; *au. s.* auditory pit; *car.* carotid artery; *f.b.* fore-brain; *h.b.* hind-brain; *hy.mn.* hyomandibular cleft; *l.* lens; *mn.* mandibular arch; *nc.* notochord; *o. c'.* outer, and *o. c''.* inner wall of optic cup; *op. v.* optic vesicle; *op. s.* optic stalk; *pit.* pituitary body; *u. j.* upper jaw; *VII.* facial nerve.

C—*ab.* outer wall of optic cup; *aus.* choroid fissure; *gl.* cavity of optic cup; *h.* space between the two walls, which afterwards disappears; *ib.* inner wall of optic cup; *l.* lens; *sn.* stalk of optic cup (rudiment of optic nerve).

i.e., that of the conjunctiva (p. 164). Mesoderm also makes its way into the optic cup through the choroid fissure, and gives rise to the vitreous humour. Lastly, the mesoderm immediately surrounding the optic cup is differentiated to form the choroid, the iris, and the sclerotic.

Thus the eye of Vertebrates has a threefold origin: the sclerotic, choroid, iris, vitreous humour, and the greater part of the cornea are mesodermal; the lens and external epithelium of the cornea are derived from the ectoderm of the head: the retina and optic nerve are developed from a hollow pouch of the brain, and are therefore in their ultimate origin ectodermal. The sensory cells of the retina—the rods and cones—although not directly formed from the external ectoderm, as in Invertebrates, are ultimately traceable to the superficial layer of ectoderm, since they are developed from the inner layer of the optic cup, which is a prolongation of the inner layer of the brain, the latter being continuous, before the closure of the medullary groove, with the ectoderm covering the general surface of the body (compare Figs. 66 and 240).

The *internal ear*, like the organ of smell, arises in the embryo as a paired invagination of the ectoderm in the region of the hind-brain, a shallow depression being formed (Figs. 66, L, 240, A, and 241, *au.* *s*) which deepens and becomes flask-shaped; and finally, as a rule, loses its connection with the external ectoderm, giving rise to a closed sac surrounded by mesoderm in which the cartilaginous auditory capsule is subsequently developed. At first simple, it soon becomes divided by a constriction into dorsal and ventral compartments, from the former of which arise the utriculus and semicircular canals, and from the latter the sacculus and cochlea.

The early development of the **alimentary canal** has already been dealt with in the case of the frog (pp. 180 and 183), and it will be remembered that the greater part

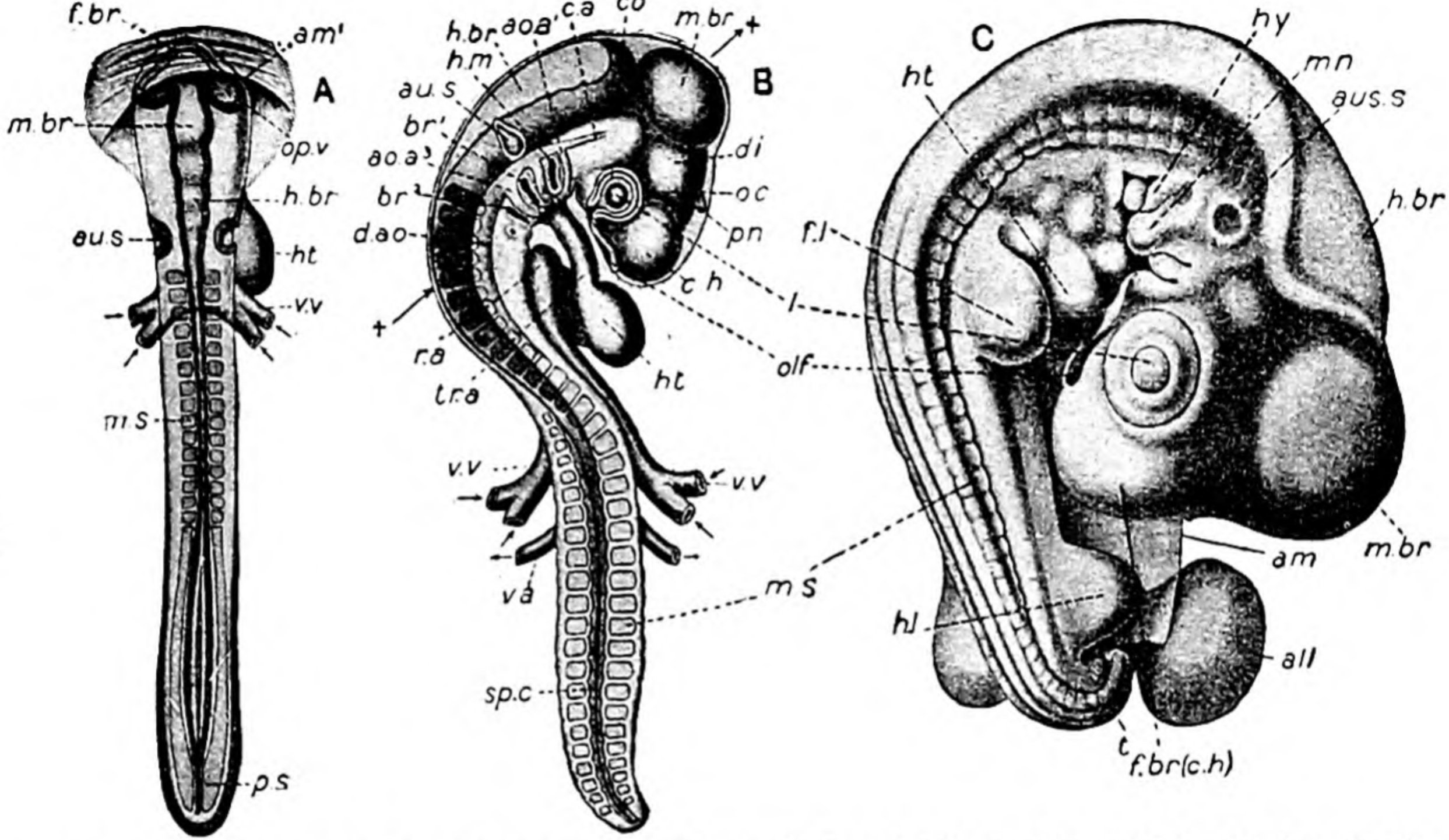


FIG. 241.—Chick embryos at, *A*, the thirty-sixth hour of incubation; *B*, the end of the third day; and *C*, the fifth day. (× 15.) (Compare Fig. 240.)

*am.*¹ head-fold of the amnion; *all.* allantois; *ao.*¹, *ao.*³, first and third aortic arches; *au. s*, *aus. s*, auditory sac; *br.*¹, *br.*², first and second branchial clefts; *am.* cut edge of amnion; *am.*¹ pro-amnion; *c. a.* carotid artery; *cb.* cerebellum; *c. h.* cerebral hemisphere; *d. ao.* dorsal aorta; *di.* diencephalon; *f.br.* fore-brain; *f.l.* fore-limb; *h.br.* hind-brain; *h.l.* hind-limb; *h.m.* hyomandibular cleft; *ht.* heart (ventricle); *hy.* hyoid arch; *l.* lens of eye; *m.br.* mid-brain; *mn.* mandibular arch; *m. s.* mesodermal segments; *o. c.* optic cup; *olf.* olfactory pit; *op. v.* optic vesicle; *pn.* pineal body; *r. a.* right auricle; *sp. c.* spinal cord; *t.* tail; *tr.a.* conus arteriosus; *v. a.* vitelline artery; *v. v.* vitelline vein. (*A* and *B*, from Marshall; *C*, from Parker and Haswell, after Duval.)

of it (*mesenteron*) is lined by endoderm, its cavity being at first bounded by the yolk below, but gradually becoming closed in by endoderm cells. When a yolk-sac is formed (dogfish, bird, mammal, Figs. 236, 242), it of course communicates with the mesenteron; but as the embryo is gradually folded off from the yolk-sac, the mesenteron becomes tubular along its whole length, and eventually the stalk of the yolk-sac becomes solid, at hatching (or birth) its point of communication with the body being marked by the *navel* (*umbilicus*). The ectodermic *stomodæum* (p. 183), which gives rise to the mouth-cavity and also to the greater part of the pituitary body, comes to communicate with the mesenteron anteriorly, and the ectodermic *proctodæum* opens into it posteriorly. The muscular and peritoneal layers of the canal are formed, it will be remembered, from the mesoderm.

The first traces of the *liver* (Fig. 66, K) and *pancreas* are seen as simple endodermic offshoots of the mesenteron, which gradually become branched in a complicated manner, the numerous lobules being more or less closely connected together by mesoderm.

The *gill-pouches* arise as paired outgrowths of the endoderm lining the pharynx, which come into contact with the ectoderm, the latter becoming perforated to form the external branchial apertures. The bars, with their contained skeletal and vascular structures, which separate the pouches, are called the visceral arches; there are similar skeletal and vascular structures in front of the first and behind the last cleft; so that, in all, five visceral arches are reckoned, with four intervening gill-clefts. Four gill-clefts appear also in the embryo of reptiles, birds, and mammals—animals in which gills are never developed (Fig. 241), but they early disappear with the exception of the first cleft, corresponding

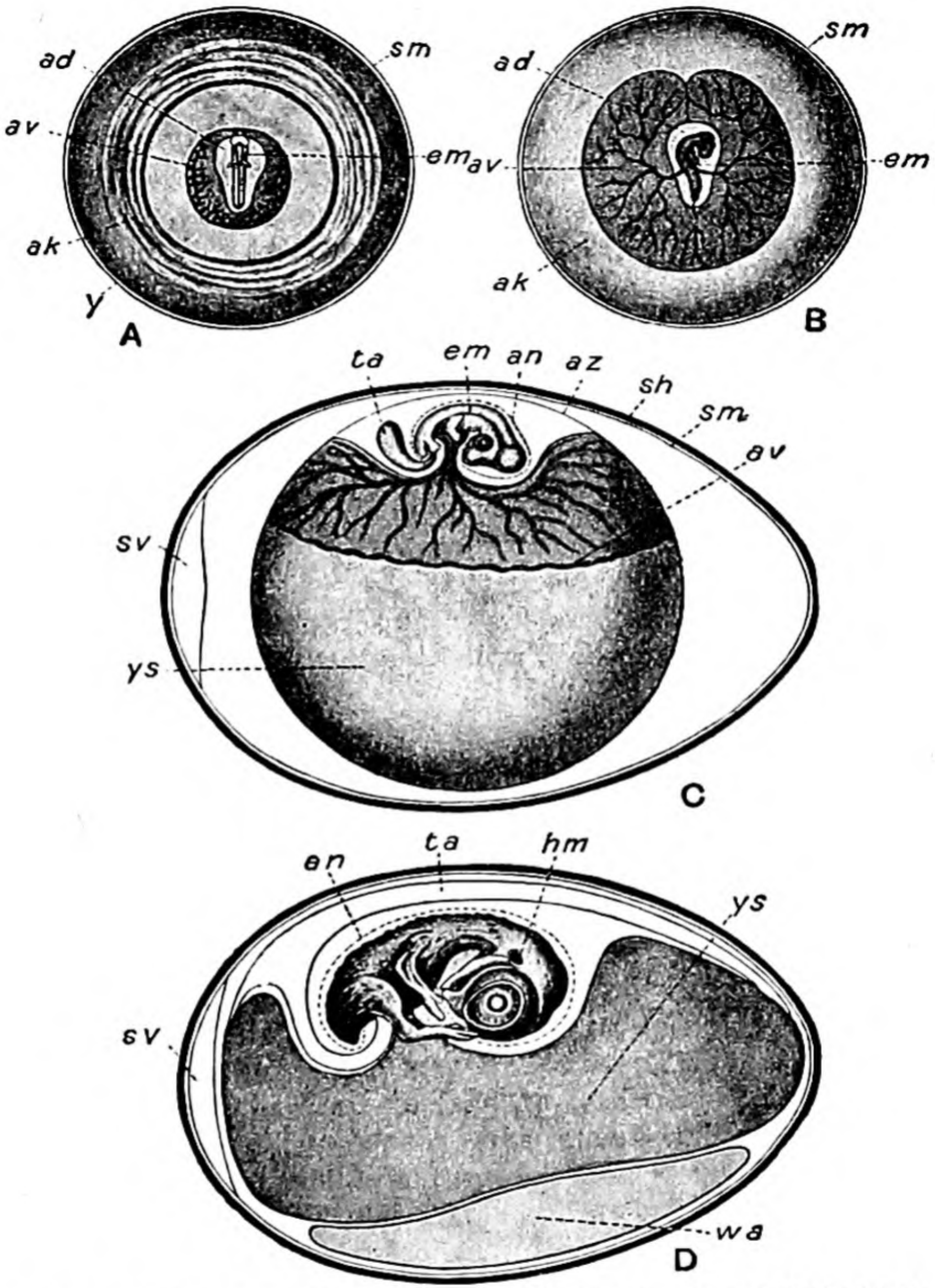


FIG. 242.—The yolk of a Hen's egg at, *A*, the thirty-sixth hour from the beginning of incubation; *B*, the third day; *C*, the end of the fifth day; and *D*, the end of the ninth day (about nat. size). (Compare Fig. 190.)

ad. area pellucida; *an*. inner or " true " amnion; *ak*. area opaca; *av*. area vasculosa (in *C* its outer margin); *az*. outer or " false " amnion (serous membrane); together with the vitelline membrane; *em*. embryo; *hm*. hyomandibular cleft; *sh*. egg-shell; *sm*. vitelline membrane (in *C*, shell membrane); *sv*. air-chamber; *ta*. allantois; *wa*. white or albumen; *ys* yolk-sac. (From Marshall.)

with the spiracle (p. 415) of the dogfish, which gives rise in all Vertebrates above fishes to the tympano-eustachian passage: the branchial skeleton, as we have seen, undergoes a corresponding reduction or modification (pp. 418 and 450). In air-breathing Vertebrates the *lungs* arise as a ventral outgrowth of the pharynx, lined by endoderm and covered by mesoderm.

FIG. 243.—A section through a Chick embryo at the end of the third day of incubation, the section being taken along a plane indicated by the two arrows and crosses in Fig. 241, *B*; the right side of the section is at a level slightly dorsal to that of the left side. (× 30.) (After Marshall.)

a. dorsal aorta; a^1. first aortic arch, in the mandibular arch; a^2. second aortic arch, in the hyoid arch; a^3. third aortic arch, in the first branchial arch; *ac*. carotid artery; *ai*. internal carotid artery; *bm*. cavity of mid-brain; br^1. first branchial arch; *ch*. notochord; *hm*. hyomandibular cleft; *hy*. hyoid arch; *mn*. mandibular arch; *mp*. muscle-plate; *ne*. ganglion of spinal nerve; *ns*. spinal cord; *pt*. pituitary outgrowth; *tp*. pharynx; *vb*. jugular vein.

The **circulatory organs** are developed from the mesoderm, the *heart* arising in the visceral layer on the ventral side of the pharynx. It has at first the form of a straight tube, developed in the chick and rabbit by the fusion of two longitudinal vessels (vitelline veins, see below), it soon becomes twisted into an S-shape, and transverse constrictions are formed dividing it into the different chambers. The auricular and ventricular portions are each at first single, but from the Amphibia onwards the former subsequently becomes divided into two by a septum, and in birds and

mammals the ventricle is similarly subdivided. The modification of the arterial arches in the examples studied has already been described (pp. 420 and 480).

In the dogfish, bird, and rabbit the dorsal aorta, in addition to its other branches, gives rise to paired *vitelline arteries*: these branch over the extra-embryonic part of the blastoderm (p. 551) which spreads over the

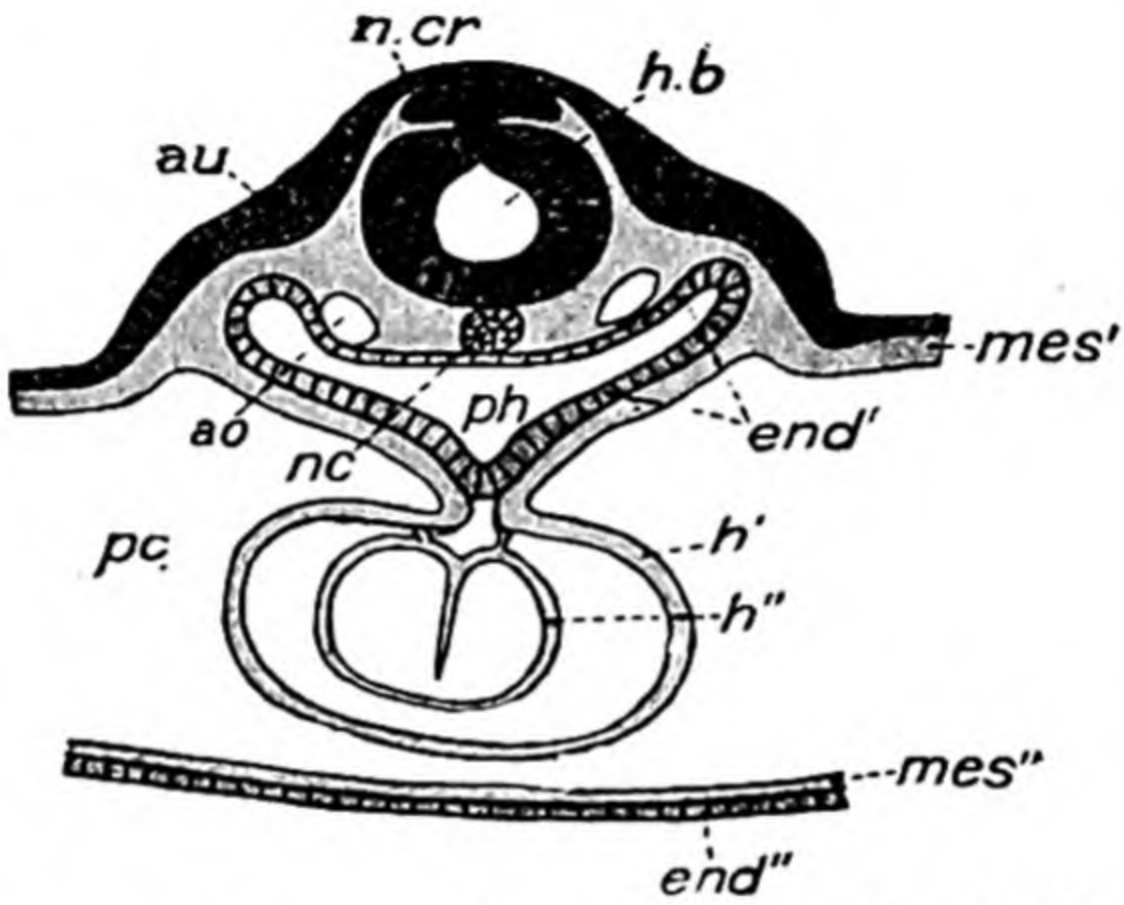


FIG. 244.—Transverse section across the head of a Chick embryo at about the fortieth hour of incubation, in the region of the hind-brain and heart. (× about 90.) *ao.* aorta; *au.* beginning of auditory pit; *end'.* endoderm of pharynx; *end''.* endoderm of yolk-sac; *h'.* muscular wall of heart; *h''.* epithelial lining of heart (the septum, which subsequently disppears, indicates the paired origin of the heart); *h.b.* hind-brain; *mes'.* parietal, and *mes''.* visceral layer of mesoderm; *nc.* notochord; *n. cr.* neural crest; *pc.* pericardial cœlome; *ph.* pharynx.

yolk-sac, and in the two former types the capillary network takes an important share in the absorption of the yolk by the embryo. From this network in the *area vasculosa* (Fig. 242) the blood is returned by splanchnopleuric *vitelline veins*, which join with a *subintestinal vein* and open into vessels which eventually give rise to the hepatic portal veins. The chief somatopleuric veins in all embryonic Vertebrates are, as in the dogfish,

the jugulars and the cardinals (Figs. 240 and 243). In all Vertebrates above the fishes, the cardinals become subsequently more or less entirely replaced functionally by the postcaval: the anterior part of one or both cardinals may, however, persist as the azygos vein or veins (*e.g.*, rabbit, p. 484).

Urinogenital Organs.—The *excretory organs*, speaking of Vertebrates as a whole, arise as a series of tubules situated along the dorsal region of the cœlome; but owing to the fact that they do not all arise at the same time and that their development is modified by neighbouring structures, there is much variation as regards these tubules and their relations. They may in general be classified into three groups, constituting what are known respectively as the *fore-kidney* or *pronephros* (Fig. 245, A, *p. nph*), the *mid-kidney* or *mesonephros* (*ms. nph*), and the *hind-kidney* or *metanephros* (*mt. nph*).

The *pronephros* appears at an early stage of development, and very rarely remains functional throughout life, though in some cases (*e.g.*, tadpole) it serves as an excretory organ in the larva; in many cases it is merely represented by vestiges (*e.g.*, dogfish, bird, rabbit). The pronephric tubules open at one end into the cœlome by ciliated *peritoneal funnels*, and at the other into a longitudinal *archinephric duct* or *segment duct* (*sg. d*), which communicates with the cloaca posteriorly. They are generally from two to four in number, are not strictly segmental, and are confined to the anterior end of the cœlome: opposite their peritoneal funnels a single large glomerulus (see p. 129) is present on either side of the body.

The *mesonephros* appears rather later than the pronephros, and extends along the greater part of the cœlome. Its tubules are segmentally arranged, and thus furnish another example of metamerism in the Verte-

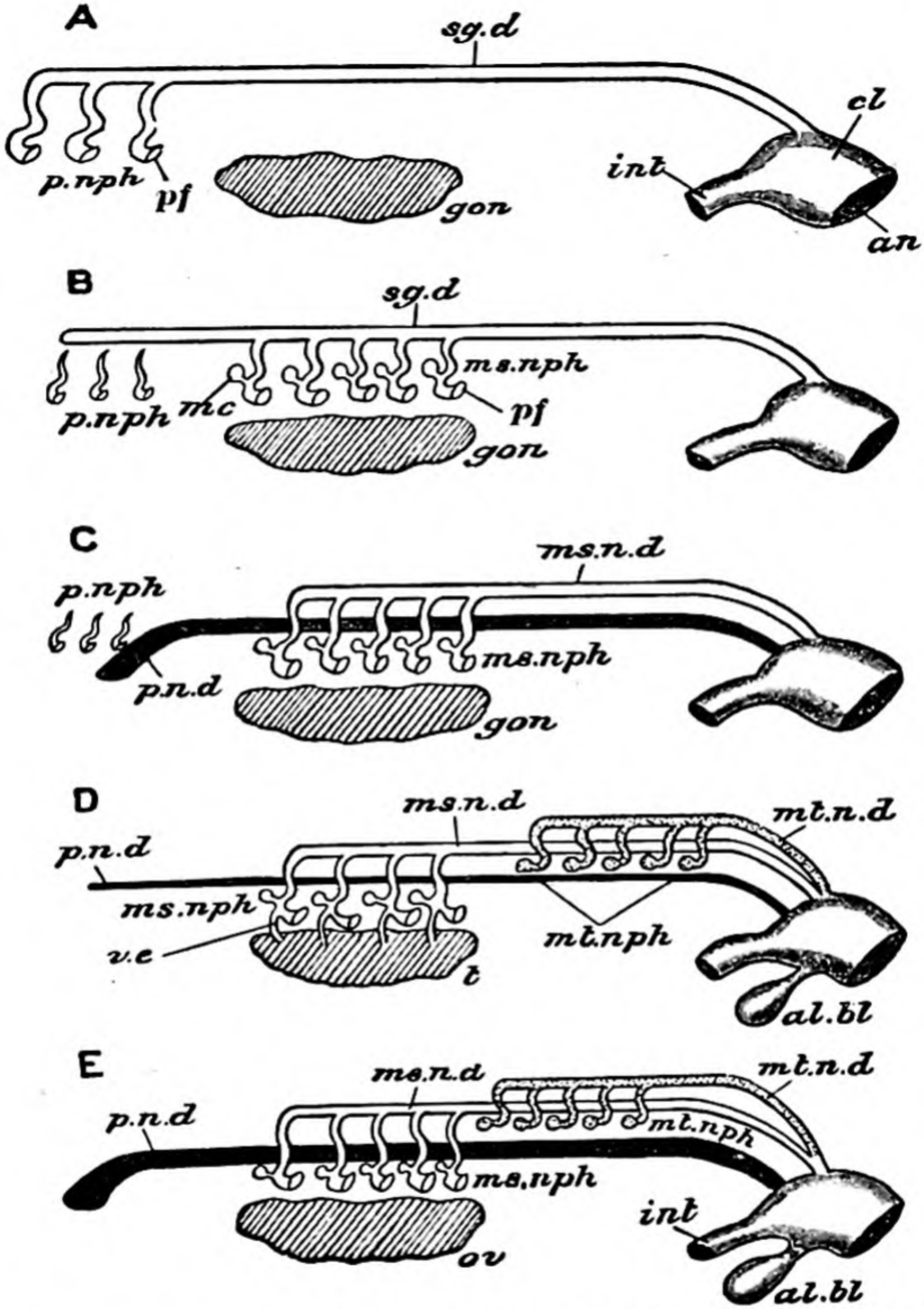


FIG. 245.—Diagrams illustrating the development of the urinogenital organs of Vertebrate.

A, pronephros in functional activity; *B*, atrophy of pronephros, development of mesonephros; *C*, condition in the adult female frog showing differentiation of Wolffian and Müllerian ducts; *D*, *E*, condition found in the higher craniate, showing *D*, development of metanephros, male type; *E*, female type.

al. bl. allantoic bladder; *an.* anus; *cl.* cloaca; *gon.* gonad; *int.* intestine; *mc.* Malpighian capsule; *mesn. d.* mesonephric (Wolffian) duct; *ms.nph.* mesonephros; *mt.n. d.* metanephric duct; *mt.nph.* metanephros; *pf.* peritoneal funnels; *ov.* ovary; *p. n. d.* Müllerian duct; *p.nph.* pronephros; *sg. d.* archinephric or segmental duct; *t.* testis; *v.e.* efferent ducts. (From Parker and Haswell's *Zoology*.)

brate body; each tubule is provided with a separate glomerulus enclosed within a Malpighian capsule (*mc*). The peritoneal funnels of the mesonephros may lose their connection with the tubules and come to open into certain veins (*e.g.*, frog, Fig. 49), or may disappear at a later stage to a greater or less extent (dogfish) or entirely (*e.g.*, bird, rabbit): at their other ends the tubules communicate with the archinephric duct, which may now be spoken of as the *mesonephric duct* (Fig. 245, *ms. n. d*, *ms. t*). In Fishes and Amphibians (Fig. 245, C) the mesonephros remains as the functional kidney throughout life, though the posterior part alone may retain the renal function and develop special ducts (dogfish), thus foreshadowing the metanephros of higher Vertebrates.

The *metanephros* is characteristic of Reptiles, Birds, and Mammals (Fig. 245, D and E). Its tubules arise later than those of the mesonephros and open into a special ureter or *metanephric duct* (*mt.n. d*), which arises as an outgrowth from the posterior end of the mesonephric duct: they resemble the mesonephric tubules except that they possess no peritoneal funnels and usually show no signs of a metametric arrangement.

In the majority of Vertebrates the *generative organs* take on a close connection with certain of the urinary tubules and their ducts (p. 173), which may thus undergo a change of function. In the dogfish the archinephric duct early undergoes longitudinal subdivision into two, one of which is retained as a mesonephric duct (now often spoken of as the *Wolffian duct*);

while the other (*Müllerian duct*), retaining its connection anteriorly with the cœlome by a persistent pronephric peritoneal funnel, assumes the function of an oviduct in the female, and atrophies in the male, though traces of it may persist in the adult. Owing to the connection which is formed between the testis and certain of the mesonephric tubules by means of efferent ducts, the Wolffian duct may now serve as a urinogenital duct (frog, p. 173); or when an *epididymis* is formed from the mesonephros (Fig. 245, D), and special ureters arise in connection with the functional renal tubules, the Wolffian duct serves as a spermiduct mainly if not entirely (mammal, p. 502).

In most Vertebrates the oviducts arise quite independently of the mesonephric ducts, each being formed as a groove of the cœlomic epithelium which becomes closed in and grows from before backwards to the cloaca, its anterior opening into the cœlome being a funnel with ciliated lips drawn out in the Mammals into fimbriated lobes. In the lower forms (Amphibia) the funnel retains its position far forward, but in others the duct becomes shortened.

In the higher Vertebrates, in which the kidney of the adult is a metanephros (p. 571), the only parts of the mesonephros and its duct which persist as more than a vestige are the epididymis and spermiduct of the male.

The *gonads* arise as ridges covered by cœlomic epithelium on the dorsal wall of the body-cavity close to the inner side of the developing kidneys. Their epithelium is known as *germinal epithelium*, and from it either ova or sperms are eventually developed (pp. 173–174, and 503).

The majority of the **muscles** are developed, as we have seen (pp. 182 and 556), from the mesodermal

segments, others arising from the parietal and visceral layers of the mesoderm.

The first part of the **endoskeleton** to be formed is the *notochord* (pp. 182 and 548), developed primarily from the endoderm, but in the chick and rabbit arising from the central part of the mass of cells continued forwards from the front end of the primitive streak where the endoderm and mesoderm are united in a secondary median fusion for some time. In the mesoderm surrounding the notohcord cartilages appear and give rise to the *vertebræ*, the notochord becoming constricted by the ingrowing cartilage and eventually disappearing more or less completely (p. 420): it at first extends into the head as far as the pituitary body (Fig. 246.) The cranial cartilages do not become segmented, but give rise to a pair of horizontal bars, the *parachordals* (*pa. ch*): these are continued forwards, diverging around the pituitary body, as the *trabeculæ cranii* (*tr*). The two parachordals and trabeculæ then unite respectively with one another, and so form a firm floor for the future

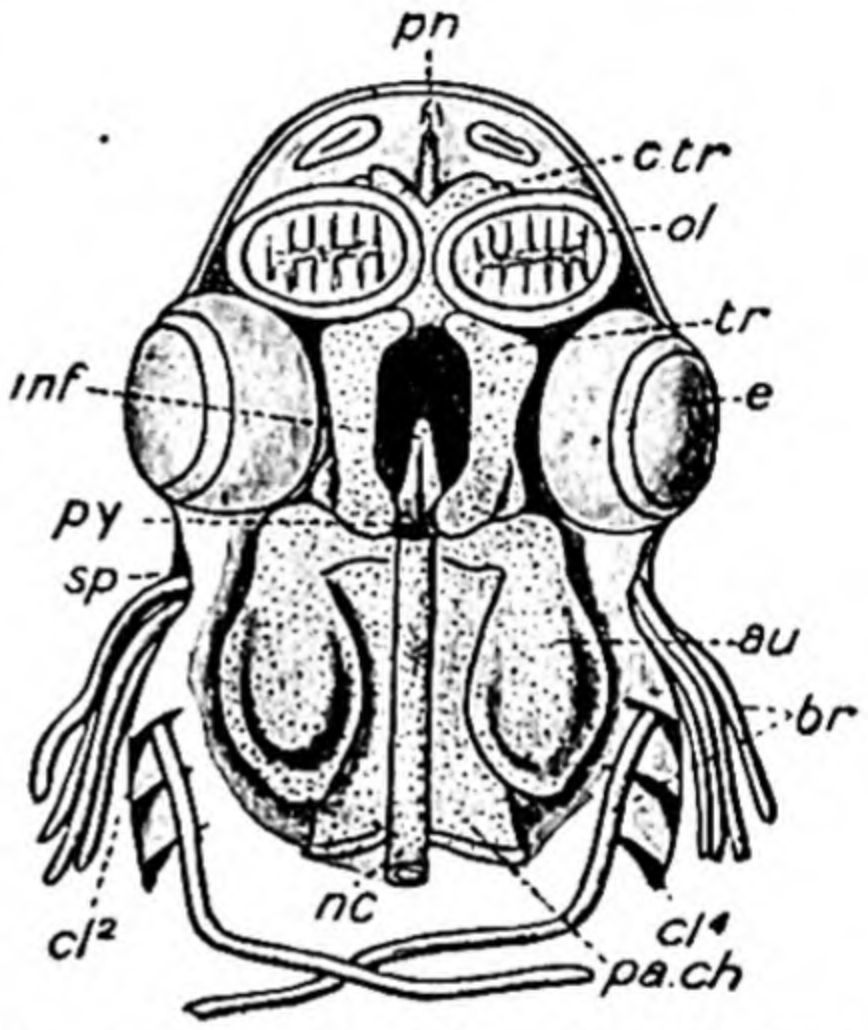


FIG. 246.—Dissection of the head of an embryo Dogfish (*Scyllium canicula*) from the dorsal side, to show the developing chondrocranium (dotted). (× 8.)

au. auditory capsule; *br.* external gills; *c. tr.* cornu of trabecula; cl^2, cl^4. gill-clefts; *inf.* infundibulum of brain (left *in situ*); *nc.* notochord; *ol.* olfactory sac; *pa. ch.* parachordal cartilage; *pn.* prenasal cartilage; *py.* pituitary body (left *in situ*); *sp.* spiracular cleft; *tr.* trabecula. (After W. K. Parker.)

brain-case: this is gradually developed by the cartilage growing up on either side and eventually meeting to a greater or less extent above the brain: there is never, however, a complete cartilaginous roof to the cranium, parts of which are only membranous and form the fontanelles (p. 41). In the meantime the cartilaginous sense-capsules are developed, the olfactory and auditory capsules uniting with the brain-case in front and behind respectively.

The *visceral skeleton* is formed as a series of cartilaginous bars within the visceral arches, the first of which forms the mandibular arch, the second the hyoid, and the others the branchial arches.

The limbs appear as small buds (Fig. 241, C) composed of ectoderm with a core of mesoderm, in which latter their skeleton arises by the formation of cartilage extending inwards to form the arches, and outwards to form the skeleton of the free portions of the limbs.

As we have seen, the endoskeleton may remain practically entirely cartilaginous in the adult (*e.g.*, dog-fish), but in higher forms extensive processes of ossification set in, certain bones replacing the cartilage to a greater or less extent, and others being formed in the surrounding connective-tissue (compare p. 41).

Development of the Amnion, Allantois, and Placenta.—We must now consider some important and characteristic structures which are developed in the embryos of Reptiles, Birds, and Mammals, and known as *embryonic membranes*. Taking the chick as a convenient example, these are formed as follows.

The blastoderm, as we have seen (p. 551 and Fig. 242), gradually extends peripherally so as to cover the yolk, and thereby becomes divisible into an *embryonic portion*, from which the embryo is formed, and an *extra-embryonic portion*, which invests the yolk-sac and takes

no direct share in the formation of the embryo. The extension of the ectoderm and endoderm takes place regularly and symmetrically; but the mesoderm, while extending equally in the lateral and posterior regions, grows forwards in the form of paired prolongations which afterwards unite, so that for a time there is an area of the blastoderm in front of the head of the

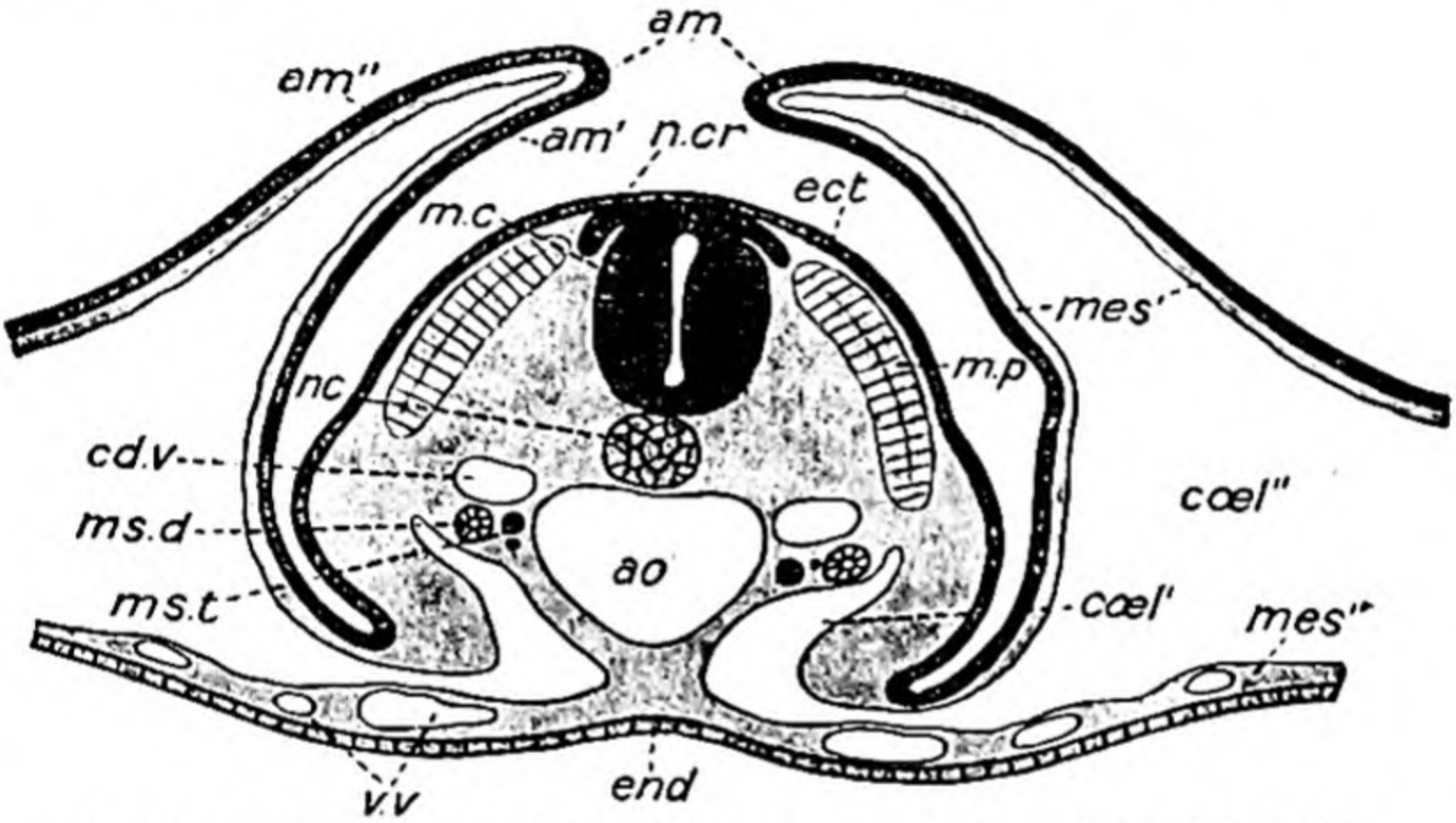


FIG. 247.—Transverse section across the body of a Chick embryo at about the sixtieth hour of incubation. (× about 90.)

ao. aorta; *am.* amniotic folds; *am'.* true amnion, and *am''.* serous membrane; *cd. v.* cardinal vein; *cœl'.* cœlome in body of embryo; *cœl''.* extra-embryonic cœlome; *ect.* ectoderm; *end.* endoderm; *m. c.* medullary cord; *mes'.* parietal, and *mes''.* visceral layer of mesoderm; *m.p.* muscle-plate; *ms. d.* mesonephric duct; *ms. t.* mesonephric tubule; *nc.* notochord; *n. cr.* neural crest; *v. v.* vitelline veins.

embryo formed of ectoderm and endoderm only and called the *pro-amnion* (p. 553 and Fig. 238, E, *pr. am*).

Before the embryo has begun to be folded off from the yolk the rudiment of one of the two embryonic membranes, the **amnion,** has appeared. A crescentic *amniotic fold* (Fig. 241 A, and 248, A, *am. f'*) arises in front of the head end of the embryo from the region of the pro-amnion: it consists at first of ectoderm only,

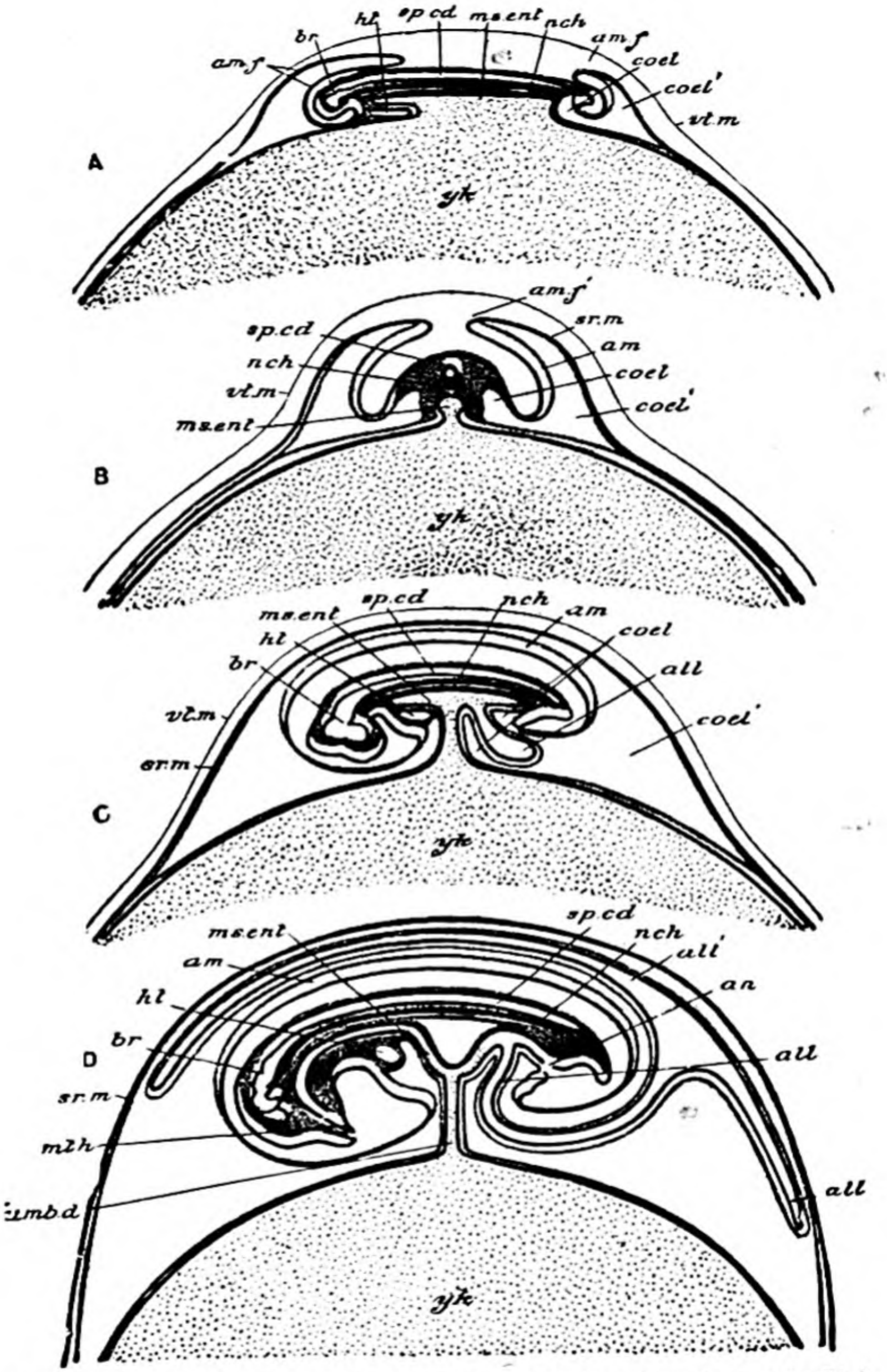


FIG. 248.—Diagrams illustrating the development of the fœtal membranes of a Bird, A, early stage in the formation of the amnion, longitudinal vertical section; B.

slightly later stage, transverse section; C, stage with completed amnion and commencing allantois; D, stage in which the allantois has begun to envelop the embryo and yolk-sac. The ectoderm is represented by a blue, the endoderm by a red line; the mesoderm is grey.

all. allantois; *all'.* the same growing round the embryo and yolk-sac; *am.* amnion; *am. f.* amniotic fold; *an.* anus; *br.* brain; *cœl.* cœlome; *cœl'.* extra-embryonic cœlome; *ht.* heart; *ms.ent.* mesenteron; *mth.* mouth; *nch.* notochord; *sp. cd.* spinal cord; *sr. m.* serous membrane; *umb. d.* umbilical duct; *vt. m.* vitelline membrane; *yk.* yolk-sac. (Reduced from Parker and Haswell's *Zoology*.)

the mesoderm not having yet spread into the pro-amnion. The fold is soon continued backwards along the sides of the body (Fig. 248, B) and a similar fold appears round the tail end (A), but in these regions (*am. f*) it consists from the first of ectoderm *plus* the parietal layer of mesoderm, *i.e.*, it is a fold of what may be called the embryonic body-wall or *somatopleure* (p. 548). Its cavity is a prolongation of the space between the parietal and visceral layers of mesoderm—*i.e.*, is an extension of the extra embryonic cœlome.

The entire amniotic fold gradually closes in above (Fig. 248, C) forming a double-layered dome over the embryo. Its inner layer, formed of ectoderm internally and mesoderm externally, is the *amnion* (*am*, and Fig. 241, *am'*), the cavity enclosed by which becomes filled with a watery *amniotic fluid*, serving as a protective water-cushion to the contained embryo. Its outer layer, formed of ectoderm externally and mesoderm internally, is the *serous membrane*, sometimes spoken of as the *false amnion* (*sr. m*, *am''*) : this comes to lie just beneath the vitelline membrane (p. 533), with which it subsequently fuses.

The second of the embryonic membranes, the **allantois,** is developed as an outpushing of the ventral wall of the mesenteron near its posterior end (Figs. 248, C, *all*, and 242), and consists, therefore, of a layer of visceral mesoderm lined by endoderm (*splanchnopleure*, p. 548). It has at first the form of a small, ovoid sac having the precise anatomical relations of the urinary bladder of the frog. Increasing rapidly in size, it makes its way, back-

wards and to the right, into the extra-embryonic cœlome, between the amnion and the serous membrane (C, D). Allantoic arteries pass to it from the dorsal aorta, and its veins, joining with the vitelline veins from the yolk-sac, take the blood through the liver to the heart (p. 568). Next, the distal end of the sac spreads itself out and extends all round the embryo and yolk-sac (D, *all'*), fusing, as it does so, with the serous and vitelline membranes, and thus coming to lie immediately beneath the shell-membrane. It finally encloses the whole embryo and yolk-sac, together with the remains of the albumen, which has, by this time, been largely absorbed (Fig. 248, D). The allantois serves as the embryonic respiratory organ, gaseous exchange readily taking place through the porous shell; its cavity is an embryonic urinary bladder, excretory products being discharged into it from the kidneys.

At the end of incubation the embryo breaks the shell by means of a little horny elevation or *caruncle* at the end of the beak. By this time the remainder of the yolk-sac has been drawn into the cœlome, and the ventral body-walls have closed round it. On the shell being broken the allantois gradually shrivels up, respiratory movements begin, the aperture in the shell is enlarged, and the young bird is hatched and begins a free life.

In the higher Mammalia the allantois takes on a further important function. The relations of the amnion and allantois in the rabbit are essentially similar to those described above in the case of the bird. But the later history of the allantois is widely different, owing to the modifications which it undergoes in order to take part in the formation of the **placenta,** the structure by means of which the fœtus receives its nourishment from the walls of the uterus, with which the blastocyst (p. 554) first becomes adherent over the future placental area by the proliferation of the cells of its outer

layer in this region, which forms irregular processes extending into the thickened mucous membrane on the dorsal side of the uterus (Fig. 249, *e'*). As the embryo develops, it sinks down and causes the vascular " yolk-

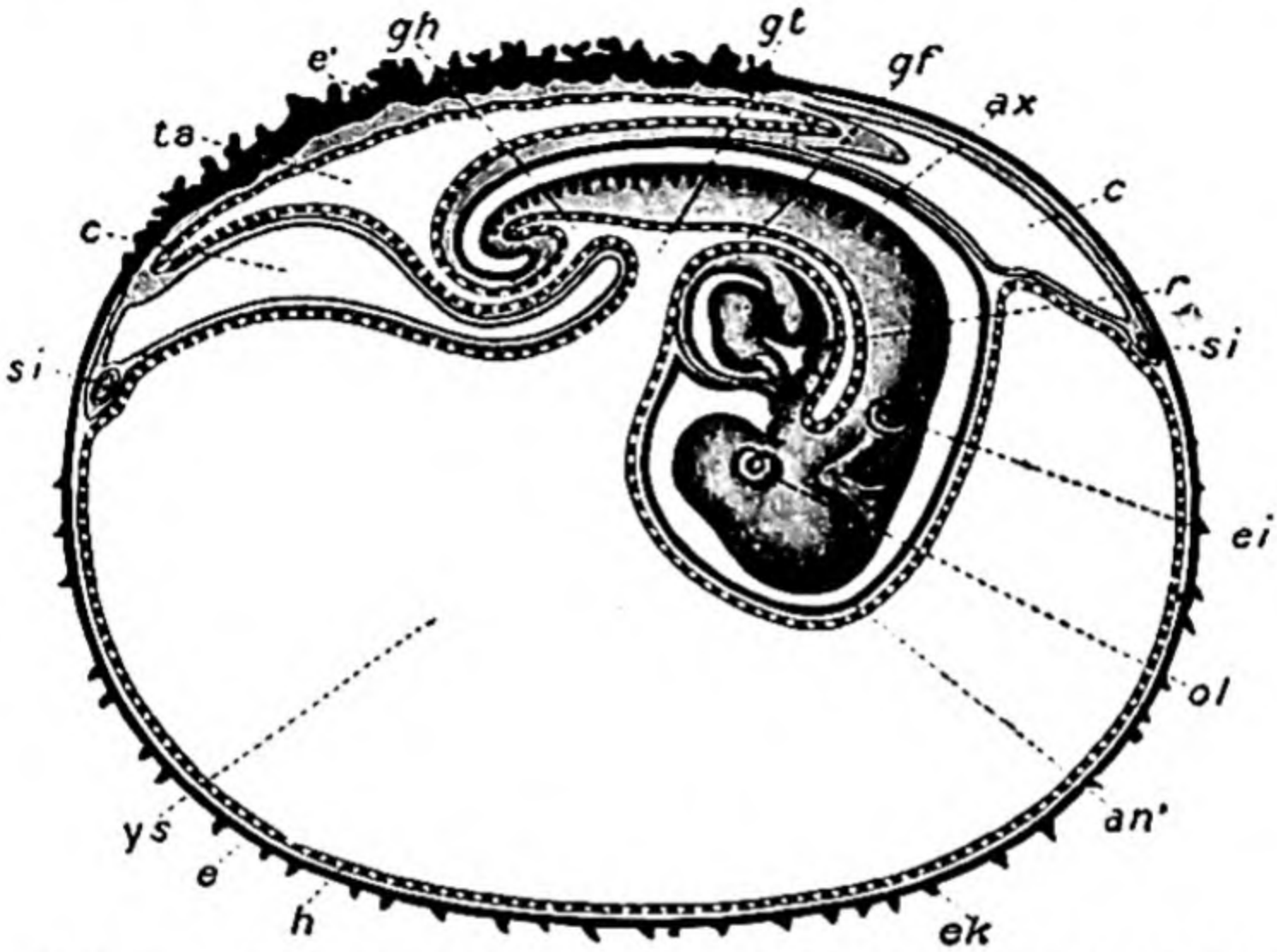


FIG. 249.—A Rabbit embryo and blastodermic vesicle (" yolk-sac ") at the end of the tenth day. The embryo is represented in surface view from the right side, the course of the alimentary canal being indicated by the broad dotted line; the blastodermic veiscle is shown in median longitudinal section. The greater part of the tail has been removed. (× 7½.)

an'. pro-amnion; *a.x.* cavity of amnion, between the inner or true amnion and the embryo; *c.* extra-embryonic portion of cœlome; *e.* ectoderm; *e'*. thickened part of *e* by which the blastodermic vesicle is attached to the uterus, and from which the development of the fœtal part of the placenta proceeds; *ei.* auditory vesicle; *ek.* ectodermal villi; *gf*, *gt*, *gh*. enteron; *h.* endoderm; *ol.* eye; *r.* heart; *si.* circular marginal vessel of area vasculosa; *ta.* cavity of allantois; *ys.* cavity of " yolk-sac." (From Marshall, in part after Van Beneden and Julin.)

sac " or umbilical vesicle (*ys*) to be doubled in and take on a flattened form (Figs. 250, *ds*, 249 and 251, *ys*): this early becomes attached to the mucous membrane of the uterus, and represents a *vitelline* or *yolk-sac placenta* such as occurs in some viviparous dogfishes;

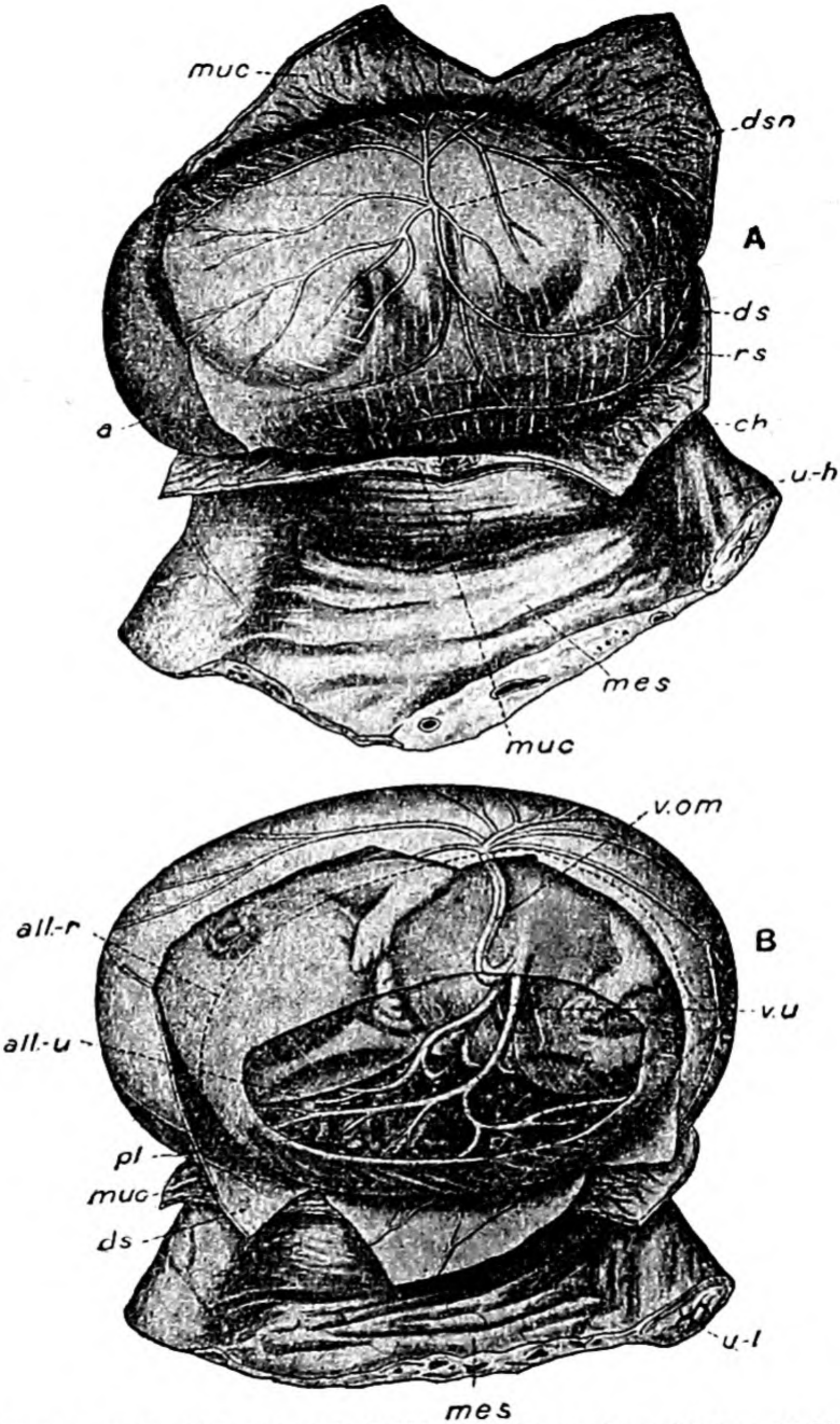


FIG. 250.—Portion of the uterus of a Rabbit containing an advanced fœtus. (× ½.) In A, the uterus has been opened and its wall reflected, and part of the "yolk-

sac" (umbilical vesicle) cut away (left of the figure) to show the underlying amnion. In B, part of the uterine wall has been removed and part of the yolk-sac and amnion cut out so as to expose the fœtus and placenta.

a. amnion; *all.-r.* dotted line indicating margin of allantois (compare Figs. 249 and 251, *ta*); *all.-u.* line along which the allantois is reflected over the placental region; *ch.* chorion; *ds.* yolk-sac; *dsn.* point at which the umbilical vessels branch out from the umbilical stalk; *mes.* mesentery of uterus; *muc.* mucous membrane of uterus; *pl.* fœtal surface of placenta covered by the distal wall of the allantois; *rs.* circular marginal vessel of area vasculosa of yolk sac; *u-h.* undilated narrow portion of uterus between two fœtus-containing swellings; *u-l.* lumen of uterus; *v. om.* vitelline vessels; *v. u.* allantoic vessels. (From Grosser's *Vergl. Anat. u. Entwick. geschichte der Eihäute und der Placenta.*)

but its nutritive function in the mammal is of only minor importance.

The *fœtal part* of the placenta is formed from the outer layer of the amnion (serous membrane) in a limited disc-shaped area covered by the thickened part of the outer layer where the distal portion of the allantois coalesces with it (Fig. 249). The membrane thus formed (*chorion*) develops vascular processes or septa—the *chorionic villi*, which are received into depressions—the *uterine crypts*—in the thickened placental folds of mucous membrane on the dorsal wall of the uterus which constitute the *maternal portion* of the placenta (Figs. 249 and 250). The fœtal portion of the placenta with its villi is supplied with blood by the allantoic vessels, and the blood-supply of the uterus is at the same time greatly increased: the fœtal and dilated maternal capillaries and sinuses are thus brought into intimate relation with one another in the placenta, being only separated by thin layers of epithelium: diffusion can thus take place between them, nutrient matter and oxygen diffusing from the blood of the mother into that of the fœtus, while excretory substances pass from the blood of the fœtus into that of the mother.

The disc-shaped or *discoidal* placenta of the Rabbit is of the type termed *deciduate*, its villi being so intimately connected with the uterine mucous membrane that a part of the latter comes away with it at birth in the *decidua*, or afterbirth, which is attached to the newly-

born young by the *umbilical cord*, consisting of the stalks of the allantois and flattened yolk-sac twisted together

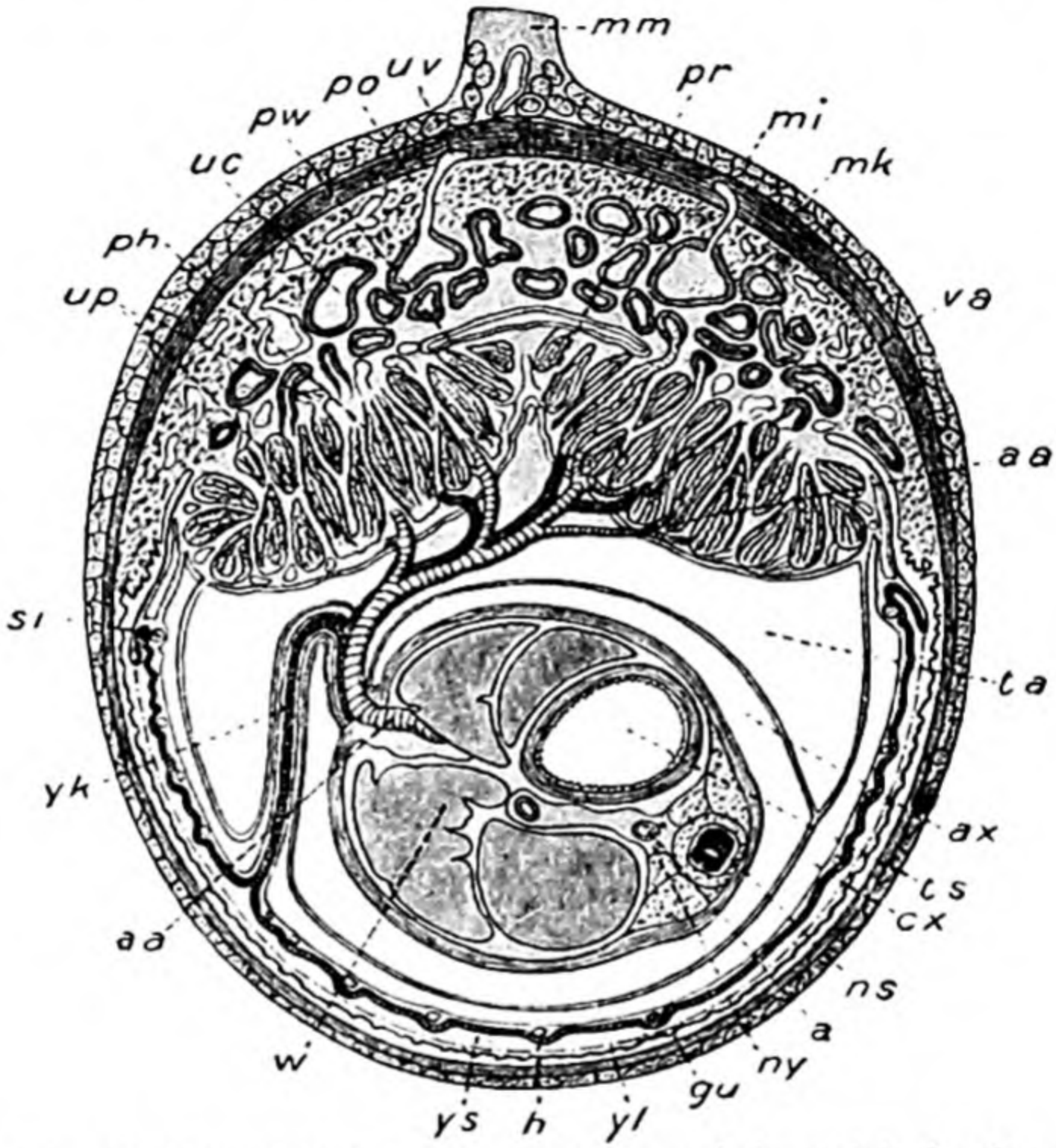


FIG. 251.—A transverse section across the uterus and the contained embryo of a Rabbit at the end of the nineteenth day. The embryo is cut transversely about the middle of the body, the section passing through the "yolk-stalk" and allantoic stalk. (× 2½.)

A, dorsal aorta; *aa*. allantoic artery; *a.x*. cavity of amnion, between the inner or true amnion and the embryo; *cx*. space between the inner and outer layers of the amnion; *gu*. uterine glands; *h*. endoderm of upper or vascular wall of "yolk-sac" (umbilical vesicle); *mi*, *mk*. outer or longitudinal, and inner or circular muscles of wall of uterus; *mm*. mesentery of uterus; *ns*. spinal cord; *ny*. sympathetic nerve-cord; *ph*. lobule of placenta; *po*. region along which the separation of the placenta occurs at birth; *pr*. inter-placental groove; *pw*. sub-placental cavity; *si*. circular marginal vessel of yolk-sac; *ts*. cavity of the allantois (see Fig. 249); *ts*. stomach; *uc*. dilated uterine capillary, with thick perivascular wall; *up* uterine or maternal sinuses of placenta; *uv*. blood-vessels of uterus; *va*. allantoic vein; *w*. liver; *yk*. stalk of yolk-sac; *yl*. dotted line representing the lower or non-vascular wall of the yolk-sac, now completely absorbed; *ys*. cavity of yolk-sac, continuous with the uterine cavity owing to absorption of the lower wall of the yolk-sac. (From Marshall.)

(Figs. 249 and 251), in which allantoic and vitelline blood-vessels are passing.

The blood-vessels at the plane of separation of the placenta and uterus are very small, and the uterus contracts so rapidly when the young are expelled at parturition that very little bleeding takes place, and the mucous membrane rapidly undergoes regeneration, ready for the next conception. The cord is gnawed through by the parent rabbit, the blood-vessels being compressed in the process; and it soon shrivels up and comes away at the navel or *umbilicus* which represents the point of connection between the fœtus and the placenta. The intra-abdominal portion of the allantois is represented by a cord or ligament, the *urachus*, which connects the navel with the apex of the bladder, so that only a small portion of the allantoic outgrowth persists in the adult, and not the whole of it, as it does in the frog.

CHAPTER III

EVOLUTION—EVIDENCES FOR EVOLUTION — THEORIES OF EVOLUTION

What Evolution means.—The student of Biology is struck with the great diversity exhibited by animal and vegetable forms now existing on this earth. He is no less struck with the resemblances in greater or lesser degree which various forms bear to one another and the marvellous adaptation which the parts of an animal or plant show to the functions which they have to perform. The phenomena of diversity in the organic world, resemblances shown by the animals and plants belonging to particular groups, and the numerous adaptations exhibited by individual organisms are all due to the fact that the forms now living on this earth did not appear as such, but were *evolved* through gradual modifications taking place during many generations, in the forms that lived before. The doctrine of Organic Evolution teaches us that species or kinds are not immutable, but are subject to changes whereby one may give rise to another, and that all existing species are the more or less modified descendants of pre-existing ones. Out of simple beginnings, when in the course of ages the earth was fit for the existence of life on it, life began, and by a continual process of evolution there came into existence not only all the marvellously adapted forms of animal and

plant life that we see to-day, but also those which have existed in the past, and some of which have left their fossil remains behind. All men of science and most other thinking men are now convinced of the truth of evolution in the inorganic as well as the organic world. Whatever differences may exist as regards the theories which have been propounded from time to time, to explain how evolution takes place, the fundamental conception of evolution is the accepted creed of all biologists, and serves as the basis on which all their attempts at natural classification depend.

Yet a student of science may not feel inclined to accept such a bold generalization, and we shall therefore briefly indicate in the following paragraphs the nature of the evidence in support of the doctrine.

Anatomical Evidence.—(1) *Data of Classification.*—The mere fact that we are able to *classify* the animals, and to express their resemblances and differences by placing them in phyla, classes, orders, etc. (see p. 197), which are more or less closely related to each other, is a strong indication in favour of a doctrine of descent. All the Chordates, for example, show certain common features of structure (see p. 406), and this is so because in the remote past they must have had a common origin. Again, although all the Vertebrates can be placed in certain definite classes, each class shows many resemblances with one or the other of the remaining classes, *e.g.*, Amphibia with the Fishes, Reptiles with Amphibia, Birds and Mammals with the Reptiles. On data afforded by Comparative Anatomy alone, the inference is irresistible that Amphibia are derived from Fishes, Reptiles from Amphibia, and both Birds and Mammals from Reptiles independently of each other. These inferences are given a vivid expression by illustrating

the mutual relationships in the form of genealogical trees, as in the following diagram :—

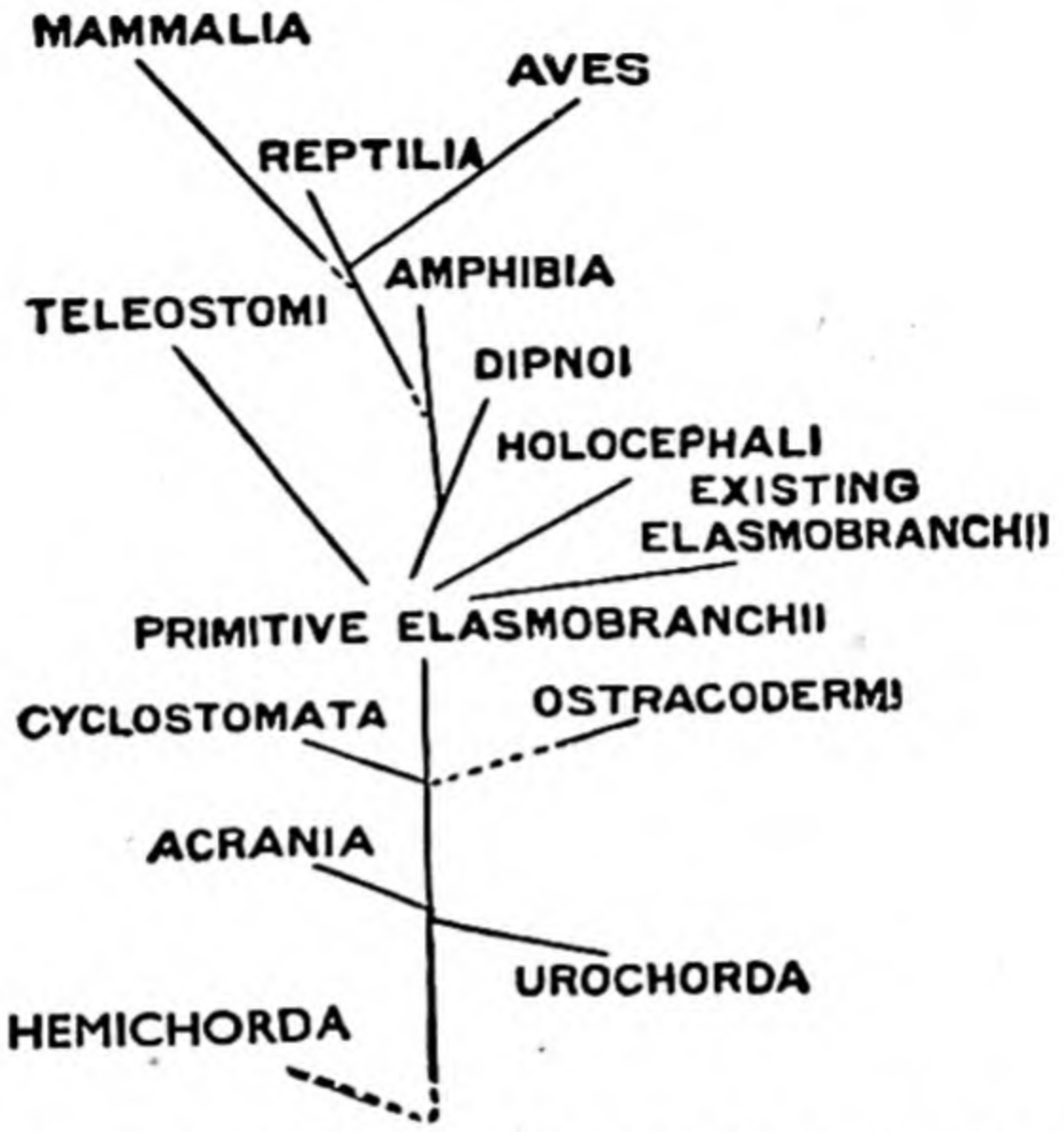


FIG. 252.—Diagram illustrating the Mutual Relationships of the various classes of the Phylum Chordata. (From Parker and Haswell's *Zoology*.)
Cyclostomata, Ostracodermi, Holocephali are names of groups which have not been referred to in this book. Acrania = Cephalochorda.

From the above we must not fall into the error of supposing that Amphibia are believed to have been descended from any existing forms of fish or conversely that any existing forms of fish would or could evolve into another set of amphibian creatures. It cannot be too strongly insisted upon that in the majority of cases it is useless to seek for the ancestors of any animal among existing forms. As far as we know, most living species are culminations—terminal branches of the great tree, not leading directly to any other form, but connected only at the fork of a branch. Of all living creatures, Amphibia no doubt show greatest resemblance to the Dipnoi (or *lung-fishes*), but it would be a mistake to think that they are descended from the Dipnoan fish existing to-day. In the tree, both the branches are connected only at the fork, and both Amphibia and

Dipnoi may be said to have evolved along different lines from a group of more primitive ancestors, which must have possessed the characters which are now the common heritage of both.

(2) *Connecting Links.*—We are often able to arrange existing organisms in progressive series, of which the extremes are connected by intermediate forms. Not only are the *connecting links* found between closely related species, but sometimes between the larger groups of the animal kingdom as well. For example, the Reptilia and the Mammalia as they exist to-day are two distinct classes of the Vertebrata, each of them having a clearly marked set of characteristic features. Yet, as mentioned in a previous chapter (p. 507), a small group of mammals known as Prototheria, including the duck-billed mole (*Ornithorhynchus*, Fig. 216) and the spiny ant-eater (*Echidna*), are found in Australia and the neighbouring islands, and are of very great zoological interest. These animals possess hairs and suckle their young ones, entitling them to be placed among the mammals, but they also possess certain other characters in which they differ from the ordinary mammals and resemble the reptiles. For example, they lay large eggs with abundant quantity of yolk, the alimentary and the urinogenital ducts open into a cloaca, and the shoulder-girdle consists of separate clavicle, coracoid, epicoracoid and scapula bones as in the reptiles, and like the latter there is a curious T-shaped bone known as the interclavicle, which is not found in other mammals. Such animals are the relics of the past, indicating the path along which the more highly organized groups may have progressed, at least for part of their journey, in their onward march of evolution.

(3) *Homologous organs.*—A common type of structure is met with, running through a whole series of forms, in

which the same essential parts, though often differently modified in accordance with differences in functions, are to be found in the same mutual relations. In all classes of the Vertebrates except the Pisces, there are two pairs of limbs, which differ greatly in form and structure according to the mode of life of the animals possessing them. In land vertebrates, whether amphibians, reptiles or mammals, the body is carried on all fours, both pairs of limbs serving as legs. In birds, on the other hand, the fore-limbs are modified into wings to enable them to fly in the air, and the hind-limbs alone support the body, while standing or moving about. The fore-limbs are also modified for flight, though in somewhat different manner in the bats and the extinct flying reptiles known as pterodactyls (see Fig. 225). In vertebrates living in water, for example turtles among reptiles and whales and seals among mammals, the limbs are modified into paddles for swimming in water. Yet these structures, however different they may be in their general form and appearance, are found on closer examination to be built on essentially the same plan; viz., the pentadactyl or five-fingered type of appendage. The wing of the Bird and of the Bat, the flipper of the Whale, the foot of the Horse, and the hand of Man are all *homologous organs*, and will be found to contain the same bony elements (compare Figs. 222, 223, 224, and 225).

The hoofed mammals, or Ungulata, afford examples of series of forms exhibiting a gradual reduction in the number of digits, accompanied by a gradual lifting of the hinder part of the foot from the ground, till we get to those cases in which the animal is seen to rest and walk on the tips of one or two toes only. Among the Perissodactyla, we find the tapir with four fingers in the manus and three toes in the pes, the rhinoceros with

three digits in each, and the horse with only the middle (third) digit in both manus and pes, with vestiges of Nos. II and IV as the functionless "splint-bones" which lie on either side of the greatly elongated metacarpal or metatarsal of the middle digit (see Fig. 223). Among the Artiodactyla, are to be found the hippopotamus, with four well-developed digits in each foot; the pig, with four digits in each foot, the two outer ones of which

FIG. 253.—The Kiwi—*Apteryx*.

are greatly reduced; the deer, with the same showing further reduction; the sheep and oxen, in which the second and fifth digits are reduced to small nodules of bone; and, lastly, the camels, in which all traces of the two outer ones have completely disappeared and only two toes are found in each foot (see Fig. 224).

(4) *Vestigial organs.*—In many cases what is a functionally active and important part in one animal is found only as a mere vestige, apparently quite useless, in an allied form. One of the most instructive examples of

these *vestigial organs* is to be found in the flightless bird known as the Kiwi or *Apteryx* of New Zealand, which is now rapidly becoming extinct. Its body is covered with coarse feathers which are so small as to look almost like hair, and the wings are so much reduced and concealed under the general plumage, that the bird appears to be without wings. The much-reduced structures are of no use as organs of flight. Yet this vestige still possesses essentially the same bony framework and the same muscles, though in a greatly reduced condition, as the complete and functional wing of the Pigeon. Numerous examples of such vestigial organs could be given. In man himself there are many vestigial structures. At the lower end of the vertebral column is found the coccyx, which represents a much-reduced tail, which in rare cases is accompanied by vestiges of muscles which in other animals are used for wagging the tail. On the chest and other parts of the body there is a complete hairy coat, such as is now possessed by the apes. The external ear is a vestige of movable ears, and there are the same muscles in connection with it which other animals use for moving their ears up and down. The only rational explanation that can be given for the occurrence of these vestigial and useless organs is that they are inherited from remote ancestors in which those organs were functional.

Embryological Evidence.—The embryos of animals of one great class or even a phylum present a great resemblance to one another, and the nearer the adult forms are in structure, the closer, usually, is the similarity in their developmental stages. If series of embryos belonging to different vertebrate types are examined, the later stages would be found to differ considerably, but the earlier corresponding stages show such a close resemblance that in many cases it is difficult for even an

experienced embryologist to distinguish between them (compare Figs. 254 and 255).

Evidence of an allied character is afforded by the fact that in the course of its development one of the higher animals sometimes appears to exhibit in successive stages features permanent in forms lower in the scale. We have

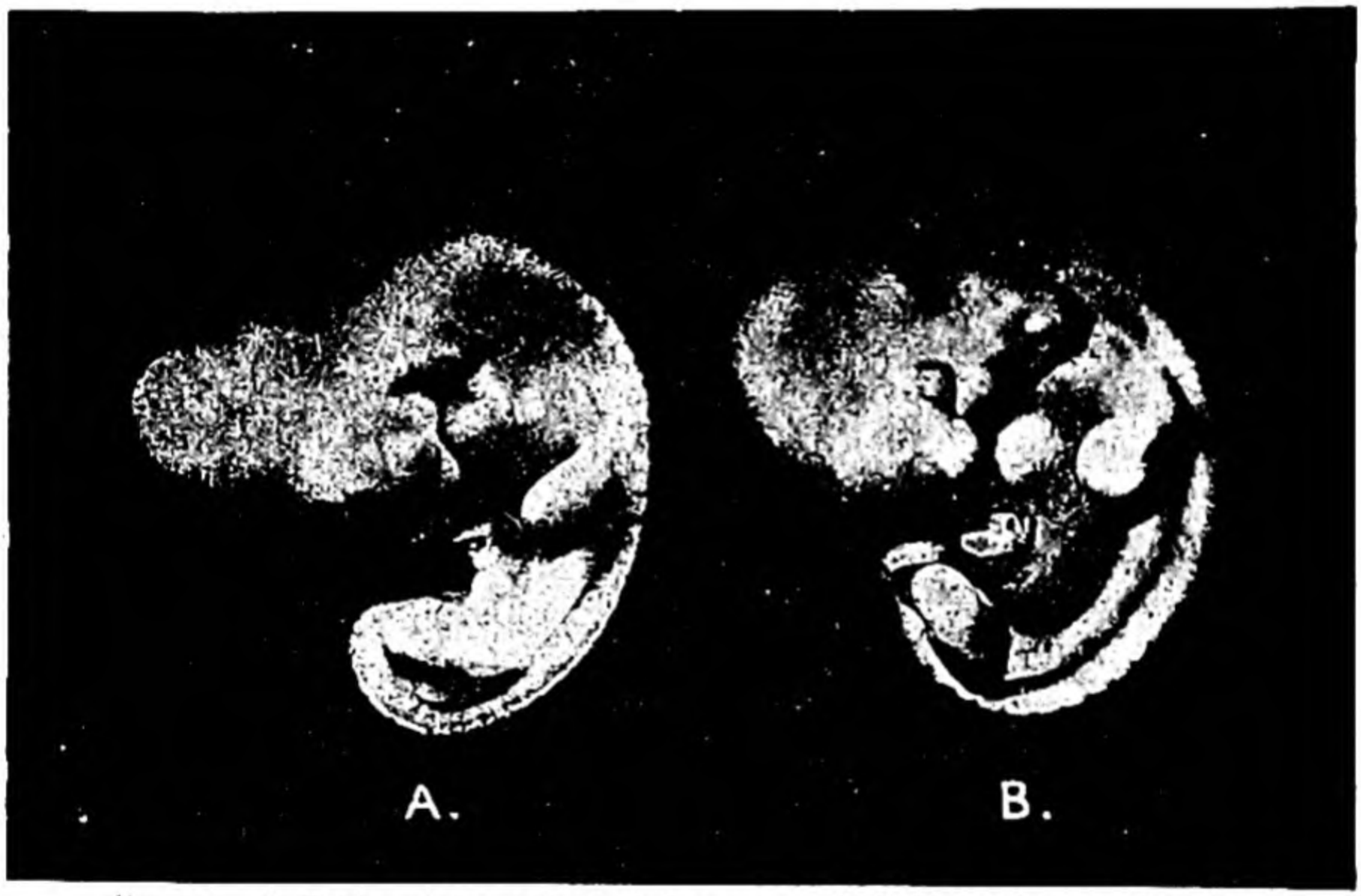


FIG. 254.—A. Chick embryo of about 5½ days, × 5. B. Rabbit embryo of about 13 days, × 5. In both cases the fetal membranes and yolk-sac have been removed. (From photographs.) (After Dendy.)

already seen how a frog in its early condition as a tadpole larva is to all intents and purposes a fish (p. 187), and explained it with reference to the recapitulation theory; which means that the successive stages in the development of the individual animal (*ontogeny*) tend to reproduce, though in a very abbreviated and often greatly modified shape, the stages through which the group

has passed in the course of its evolution from lower forms (*phylogeny*). In the case of the tadpole it might be argued that it possesses gill-clefts, gills, and fish-like circulation, because for the time being it is an aquatic creature, and not necessarily because a frog is descended from fish-like ancestors. But what of the birds and the mammals, where the embryo is never exposed to an aquatic environment, and always develops protected within the egg-shell in the birds, or within the uterus of the mother in the mammals? It is indeed truly remarkable that the embryo of a Mammal presents at an early stage visceral arches and clefts of a Fish, and has a blood-circulation in accordance with this; while at a later stage it exhibits in these particulars some resemblance to an Amphibian, later on to a Reptile, and only when development is further advanced takes on its special mammalian characters.

FIG. 255.—Human embryo, between twenty-seven and thirty days old. (After His, from *Gray's "Anatomy"*; Longmans, Green & Co., Ltd.)

Certain stages of development are common to all metazoan animals, and the inference is therefore drawn that these must represent ancestral stages through which the Metazoa as a whole passed in the dim youth of their evolutionary career. Every individual starts its existence as a single cell, and immediately after fertilization the ovum begins to segment into two, then four, then

eight, sixteen, and so on, individual cells which remain attached to one another, forming a solid aggregate known as the morula. Further segmentation produces a hollow blastula, the cavity within being the segmentation cavity or blastocœle. The next stage is that known as the gastrula, in which the embryo becomes two-layered, with a full differentiation into two distinct tissues composed of cells, the primary requisite of a metazoan animal. This is generally the result of an inpushing or invagination of the cells at one pole of the blastula into the blastocœle, more or less obliterating it (see Fig. 235). Various methods of gastrula formation are found in different animals, but the fact remains that up to this point all metazoan development, whatever the ultimate result, follows the same or strictly parallel roads. "Now we come to the parting of the ways, when the least related go each their several roads, which ultimately branch into as many byways as there are forms of life. The nearer of kin the creatures are, the later is their embryonic divergence." (Lull.)

Palæontological Evidence.—The study of existing remains of past life on this earth called fossils, is known as Palæontology. Let us inquire, what evidence has this study to offer in favour of the doctrine of evolution?

The materials of which the solid crust of the earth is made up, *i.e.*, masses of mineral matters of various kinds such as granite, sandstone, coal, clay, chalk, are, in the language of geology, all spoken of as rocks. The rocks are divided into two chief kinds, viz., *igneous* and *sedimentary*. The former include rocks like granite and basalt, which were formed as the result of the cooling of molten matter, of which the earth was probably at one time composed. The latter were formed by the slow acculumulation of material derived from the wear and tear of other rocks or from organic remains, and

were deposited layer after layer under water. The sedimentary rocks, from their occurring in regular layers or strata, are also known as *stratified rocks*, and limestone, sandstone and coal are examples of such rocks. Gravel, sand or mud, laid down in layers, became in course of time hardened by the weight of subsequent

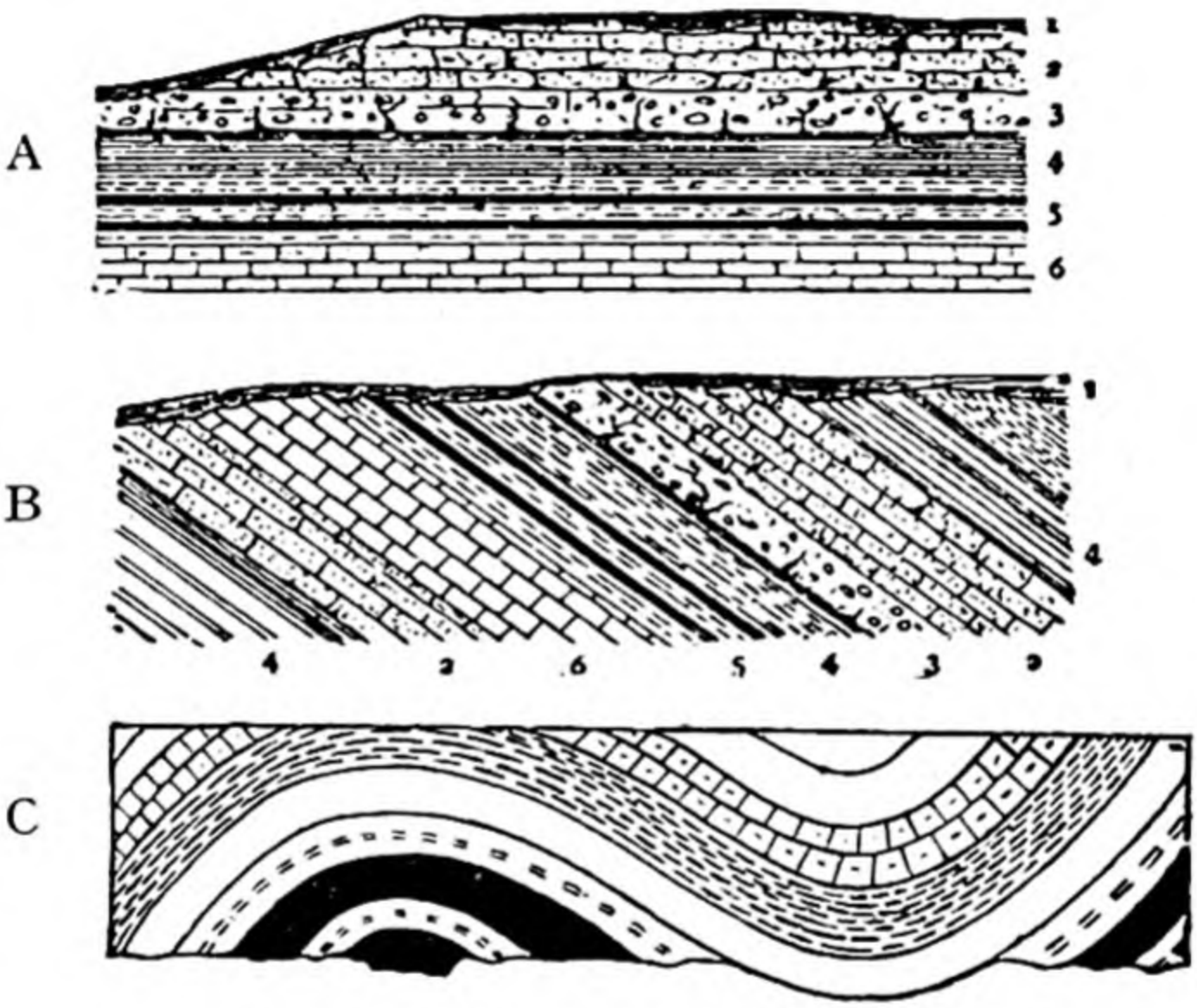


FIG. 256.—Stratified Rocks. (After Dennis Hird.)
1. Soil; 2. Sandstones; 3. Conglomorate; 4. Shales; 5. Coals; 6. Limestones

deposits, and strata are therefore found to be superimposed on one another. Sometimes they lie almost flat, as in A of Fig. 256, but, as the result of volcanic action and irregular contraction of the earth's crust, the layers are often found to be tilted at various angles (as in B) or even curved or contorted (as in C). Rocks originally deposited on the bed of the sea have

been raised up to form dry land or raised so far above sea-level as to form mountain ranges. The occurrence of fossils of marine forms in the deposits forming these mountain ranges is an unmistakable evidence that these mountains were at one time the bottom of the ocean. The igneous or unstratified rocks, for they have no regularity of position or arrangement, pierce through the layers of other rocks, or even overlie them in broad, vast masses (Fig. 257, *b*). There is still a third kind of rock, called the metamorphic or altered rocks. They are formed out of stratified or unstratified rocks, as the result of the very great heat and pressure to which they

FIG. 257.—*a*. stratified; *b*. unstratified rocks. (After Dennis Hird.)

have been exposed. The common roofing-slate is a good example of this kind of rock.

For the purposes of our inquiry, the stratified rocks only are important, as the unstratified rocks contain no fossils. It is obvious that in any series of stratified rocks, the more superficial layer is of a later period than the one below it. But different kinds of deposits are not found to occur in the same order in different parts of the earth. The geologists have, however, compared the series of stratified rocks found in different parts of the world with one another, and, by the aid of the assemblages of fossils which they contain, recognized a number of well-defined epochs in the geological history of the earth. Right below the series of stratified rocks is a vast thickness of rocks, in which no fossils have

been met with. This thickness signifies a period of time extending over millions of years, probably equalling in duration all the subsequent geological periods put together. Of the evolutionary history during this vast pre-Cambrian epoch nothing is known. These rocks were probably originally sedimentary and contained the most valuable evidence concerning the evolution of the different phyla of the animal and the vegetable kingdoms, but owing to the action of pressure and heat, their character has been profoundly altered and all the fossils originally contained in them destroyed. All the subsequent deposits are still found to contain organic remains to a greater or less extent, and the countless millions of years of earth's history signified by them are divided into three great eras, viz., palæozoic or primary, mesozoic or secondary, and cainozoic or tertiary. Each of these is subdivided into a series of epochs, as shown in the table on the next page, in which are also mentioned the relative duration of each as indicated by the estimated thickness of the stratified rocks.

If evolution has taken place, the uninitiated student may feel inclined to think, we ought to be able to find in the rocks belonging to the various geological formations a complete series of animal and plant remains representing all the stages in the evolution of the highest forms from the lowest ones. Beginning with those strata in which evidence of life first appears, we ought, it might be supposed, to be able to trace upwards, through all the series of fossil-bearing strata, continuous unbroken lines of descent showing the gradual evolution of all the various forms of animal and plant life. If such a complete geological record existed, it would undoubtedly be the most conclusive direct evidence of the course which evolution has actually taken. But that is not the case,

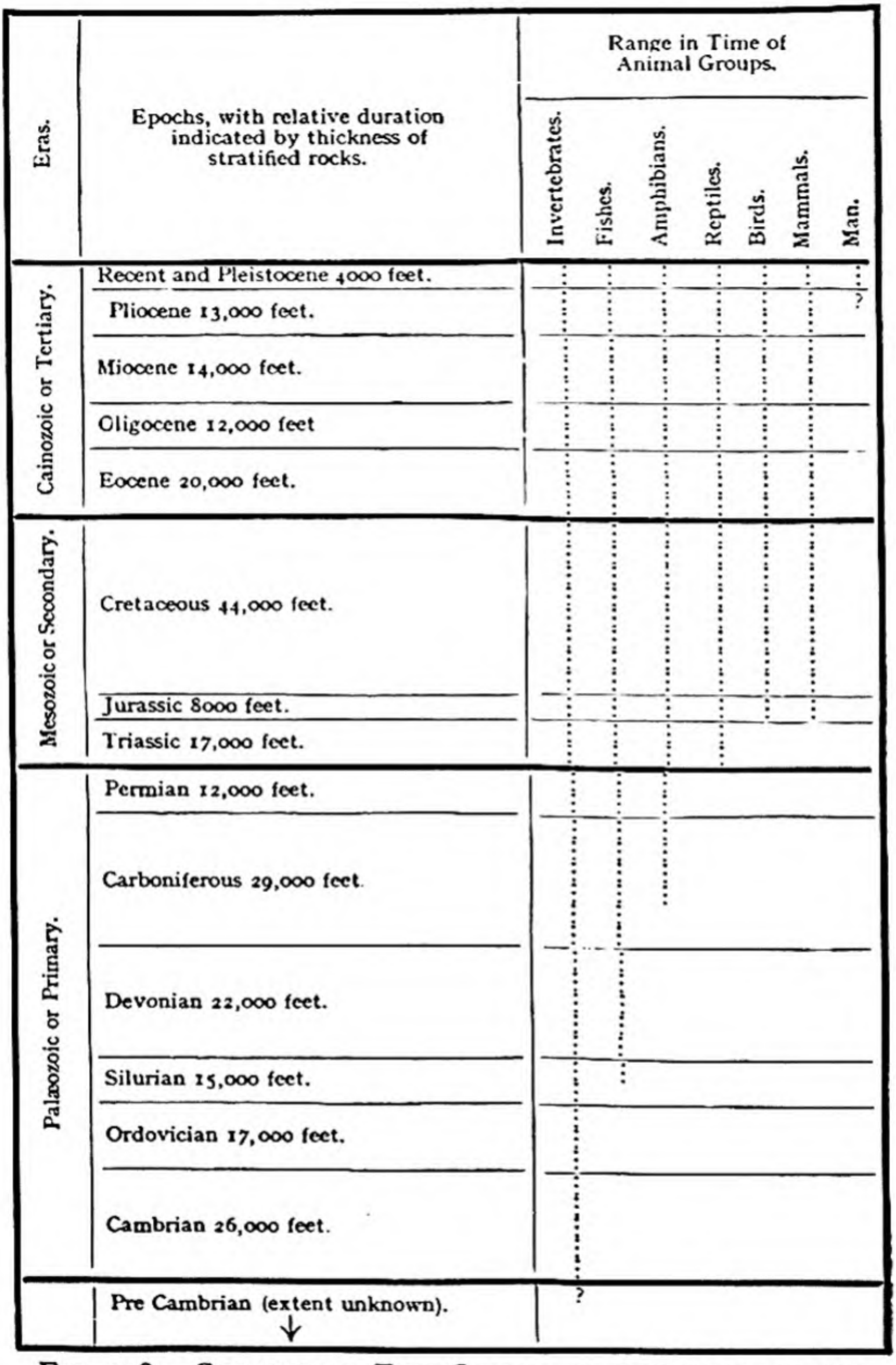


FIG. 258.—GEOLOGICAL TIME-SCALE, AS INDICATED BY THE STRATIFIED ROCKS. (After Dendy.)

and the *imperfection of the geological record* is due to many causes, which are thus summed up by Dendy :—

"It must have been imperfect when first laid down, for the great majority of animals disintegrate and pass away without leaving any recognizable remains behind them at all. In most cases it is only hard skeletal structures that have any chance of being preserved. Bodies composed entirely of soft tissues, such as jelly-fish and many worms, are rarely represented by fossils. Even hard structures, such as animal skeletons, will only be fossilized if they happen by some fortunate chance to find their way to some place where rock formation of a suitable kind is going on. The remains of land animals may be carried by rivers to some sea or lake and buried in a suitable accumulation of mud or sand, but it is more likely that they will not. Marine animals, provided they have hard skeletons, have, of course, many more opportunities of attaining a lasting monument, and we often find great thicknesses of rock, such as chalk and limestone, composed almost entirely of their remains.

"Even when the record has been successfully established, however, it is liable to destruction by various agencies. The rocks containing it may be lifted above sea-level and planed right away by sub-aerial denudation, or they may be sunk so far beneath later accumulations as to be profoundly altered by the action of heat and pressure, by which means any fossils which they contain may be completely destroyed. Then, again, we must remember that only a relatively small proportion of the earth's crust is accessible for investigation. Deep-lying rocks may be brought to the surface by upheaval, and denudation of overlying strata, or they may be reached by deep mining, but we know practically nothing of the strata which now lie beneath the bed of the sea, and

even the dry land has only been tentatively scratched by inquisitive man in a few places."

As mentioned above, the earlier portions of the record have apparently been completely destroyed, so that already in the Cambrian epoch highly organized invertebrate animals belonging to diverse phyla are found to have been in existence, but from this period onwards the geological record affords abundant evidence to show that the higher groups of animals and plants appeared on the earth in the order which definitely supports the view, that the higher forms must have evolved from forms of a lower and more generalized type that existed before them. To illustrate this point let us take the Vertebrata, the different classes of which seem to have evolved within post-Cambrian times.

There is no evidence of the highest class—the Mammalia—earlier than the Triassic period of the Mesozoic era. Birds appear for the first time in deposits of Jurassic age, and are therefore more recent than the oldest mammals; but birds are very highly specialized vertebrates, and both classes seem to have evolved from lower forms independently of each other. The earliest known fossil bird *Archæopteryx* is itself highly evolved, and no trace of more primitive birds has been found. Reptiles extend as far back as the Permian. Amphibia begin to occur in the Lower Carboniferous; whilst typical fish appear first in the passage beds between the Upper Silurian and the Lower Devonian. Within each of these classes a progress is usually traceable from older, more generalized types, along diverging lines, to the various specialized forms existing at the present day. In certain cases among the mammals a number of closely related stages have been discovered from different formations, which taken in their chronological order show a gradually increasing specialization of structure. Thus

the ancestry of horses, elephants, camels, and many other families has been fairly satisfactorily worked out. One of the best-known examples is that of the horse, and may be referred to very briefly here. On comparing the foot of the horse with its single toe with that of other Ungulates in which three or five toes are met with (Fig. 223), the inference is natural that the single-toed limb must have arisen from the primitive pentadactylic type by the gradual reduction and disappearance of all the digits except the middle one. A large number of fossil remains of horse-like animals have been found in the tertiary formations of Europe and America, and a very complete series of stages in the evolution of the modern horse discovered, which actually show this reduction and disappearance of the digits and thus confirm the inference drawn from the study of comparative anatomy. Largely through the efforts of Marsh a collection of fossil forms was assembled together which proved the first documentary record of the evolution of a race. This classic collection was studied by Huxley, who pronounced it to be "demonstrative evidence of evolution." The figure on the next page is reproduced from Huxley's works, and illustrates the important structural peculiarities of a number of fossil forms which are considered to form the fossil pedigree of the modern horse. The gradual reduction and suppression of lateral digits both in the fore- and the hind-limb through this series of forms will be noticed at once, and, what is no less interesting, the gradual reduction of ulna in the fore-limb and of fibula in the leg, and the increasing complexity of the molar teeth has been taking place in the same forms, side by side with the reduction in the number and length of the toes. It will be noticed that the ancestral form met with in the Miocene and termed *Mesohippus* has three toes in front, with a large splint-like rudiment representing the little finger, and three toes behind. The still older

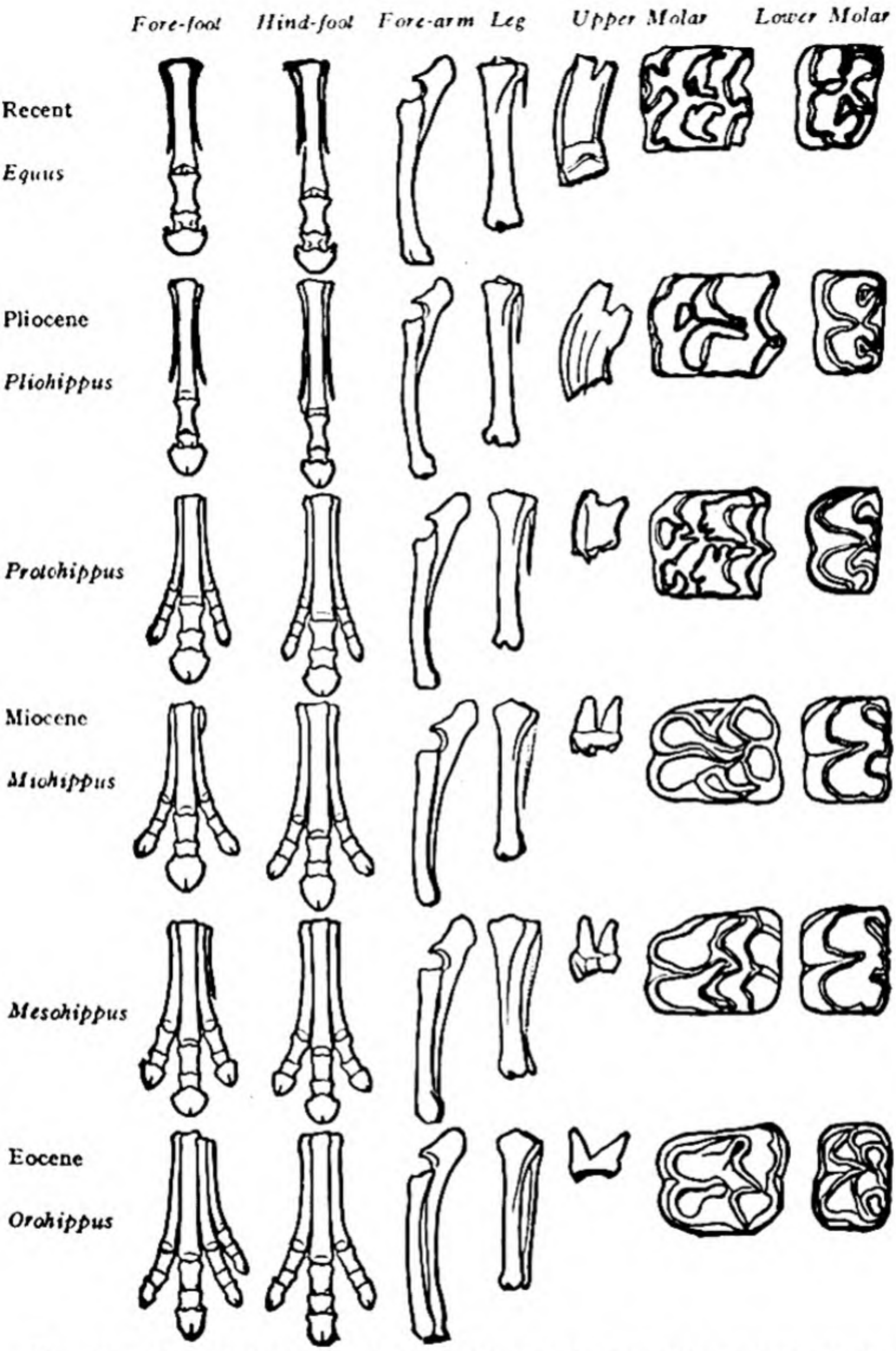


FIG. 259 —Some representative fossil remains which throw light on the ancestry of the Horse. (After Huxley.)

Orohippus, which comes from the Eocene formation, has four complete toes on the front limb and three toes on the hind limb. After examining this series of forms Huxley prophesied that when the still lower Eocene deposits have yielded up their remains of ancestral equine animals we shall find a form with four complete toes and a rudiment of the innermost or first digit in front, and with three digits and a rudiment of the fifth digit in the hind-foot, and this anticipation was more than justified only a few months later by the discovery by Marsh of another genus of equine mammals (*Eohippus*) from the lowest Eocene deposits.

It may also be mentioned here that in some cases—notably in the Amphibia, Reptilia, and Aves—the orders which were the first to make their appearance have become totally extinct, and have been succeeded by other orders belonging to these classes which made their appearance on the scene at a comparatively late period.

Theories of Evolution.—After having examined the evidences for evolution, we shall now consider some of the theories that have been propounded to explain how evolution could have taken place. Of these it will be here necessary to refer to only three, namely, those which we owe to Lamarck, Darwin, and De Vries.

The Lamarckian Theory.—This was the first important attempt to solve the problem of the means by which evolution has taken place. Lamarck published his views in his *Philosophie Zoologique* in 1809. He held the view that evolution of new forms takes place through changed conditions of life bringing about a change in habits, involving the use of new parts or a different use of old parts, which results finally in the production of new organs and the modification of old ones. He attributed considerable influence to the use and disuse of organs, and held that the development and efficiency of organs are constantly in proportion to the use of

these organs. He further held that all that has been acquired, traced out, and altered during the course of their life (whether as the result of the direct action of environment or indirectly through use and disuse of certain parts to suit new requirements) is preserved by generation, and transmitted to the new individuals which originate from those which have experienced these modifications.

To illustrate these views, we may refer to Lamarck's account of the influence of habits on the remarkable form and stature of the giraffe. This animal lives in the interior of Africa, in places where the earth, almost always arid and without herbage, obliges it to browse on the foliage of trees and to make continual efforts to reach it. As a result of this habit, maintained for a long time in all the individuals of its race, the fore-limbs have become much longer than the hind ones, and the neck has become so much elongated. Similarly the stretching of the body in the ancestors of snakes as they made their way through vegetation led to its permanent elongation, and the disuse of the limbs caused their gradual reduction and ultimate disappearance.

There are three distinct factors involved in evolution according to Lamarck, viz., *environmental influences* on the organism, *use and disuse* of organs, and, lastly, the *inheritance of acquired characters*, that is, of changes taking place during the lifetime of an individual. Of these there is a great deal of justification for a belief in the operation in nature of the first two factors—though not necessarily as causal agents for the origin of new species—and certain difficulties in the way of the acceptance of the truth of the last assumption (see p. 624). Even if acquired characters were shown to be transmissible, the other Lamarckian factors would still be inadequate to account for the development of all the various groups of animals and plants.

During the present century interest has again revived in the Lamarckian theory, and some experimental evidence is forthcoming to show that the form, colour, size, etc., of an individual may be modified by environmental influences, and the descendants of such parents may vary to a greater or less extent from the original type. Tower found that exposing the young stages of potato beetles to extreme conditions of moisture and temperature produced a marked change in the offspring, and these modifications were inherited. There was no direct effect on the bodies of the animals that were subjected to the extreme conditions, but a change was induced in the chromosomes of the cells that later became germ cells. Similarly Agar found that specimens of *Simocephalus*, one of the water-fleas, reared in a culture of green flagellate protozoa developed a curious abnormality, inasmuch as the lower edge of the carapace became reflexed outwards, and that the parthenogenetic eggs laid by such individuals when transferred to ordinary water developed into progeny which also showed the abnormality. But succeeding broods showed the peculiarity less and less, and eventually not at all. He thus concluded that the abnormal conditions, while affecting the adult, had also affected the eggs within the body of the adult. Similarly subjection of various organisms to the influence of X-rays has been shown to produce changes in the chromosomes of germ-cells and in the chromosomes in the nuclei of the somatic cells of the offspring produced from them. Many other cases of the direct influence of the environmental changes on the germ-cells and the transmission of such induced modifications are known, and are cited by the Neo-Lamarckians as evidence in favour of the Lamarckian theory. But a convincing proof of the inheritance of acquired characters or somatogenic variations is still lacking.

Darwinian Theory.—In 1858 Charles Darwin and Alfred Russel Wallace simultaneously published a very consistent and convincing explanation of evolution known as the theory of Natural Selection. In the year following was published Darwin's epoch-making book, *The Origin of Species*, which succeeded in converting the whole scientific world to a belief in the general doctrine of evolution. In nature every animal and plant form shows an excessive rate of multiplication, and consequently a keen *struggle for existence* ensues. There is also the universal occurrence of variations—that is, no two organisms, however closely related they may be, are precisely alike. Some individuals show favourable variations, others do not. Consequently, it is not merely a question of chance, as to which individuals will survive in the struggle for existence. It is the *fittest that survive*, and the less well-adapted perish. Or, in other words, *nature*, *i.e.*, the conditions under which organisms exist, *selects* and preserves certain variations as they arise, by weeding out their less well-adapted competitors, very much as the breeder or the gardener selects variations in domestic animals or cultivated plants. This is called *Natural Selection*. The main points in the theory of Natural Selection are clearly stated in the following chart :—

Proved facts.	Consequences.
A. Rapid increase in number B. Total numbers stationary	Struggle for existence.
C. Struggle for existence D. Variation with heredity	Survival of the fittest.
E. Survival of the fittest F. Change of environment	Structural modifications.

FIG. 260.—Wallace's Chart of the Theory of Natural Selection.

In order fully to comprehend the theory of Natural Selection, let us examine the factors concerned a little more closely.

Prodigality of Production.—The productivity of all living organisms is far beyond the ultimate numbers which can possibly survive, and the reason is this: organisms at their lowest rate of increase reproduce in geometrical ratio, whereas the space they may occupy and the available food supply remain constant. The elephant is the slowest breeder among mammals, but Darwin calculated that a single pair beginning to breed at thirty years and continuing to do so until a century old would produce on the average six young ones and would have in 750 years, barring accident, nineteen millions of descendants. A rabbit, on the other hand, may have six young in a litter and four litters in a year, and the young may begin to breed at six months, a vastly more rapid rate of increase.

With the invertebrates the prodigality of production may be much greater. Huxley estimated that the descendants of a single green fly, if all survived and multiplied, would at the end of one summer weigh down the population of China. Common house-flies would in the same time—six generations of three weeks each—occupy a space of about a quarter of a million cubic feet, allowing 200,000 to a cubic foot. An oyster may have as many as 60,000,000 eggs. If the progeny of a single oyster survived and multiplied and so on until there were great-great-grandchildren, these would number 66,000,000,000,000,000,000,000,000,000,000,000, and the heap of shells would be eight times the size of the earth.

Woodruff, in his study of *Paramecium*, maintained a race for five years, the descendants of one wild individual. In the five years there were 3,029 generations, the mean rate of reproduction being three divisions in

twenty-four hours. All the descendants in each generation could not possibly be preserved and given a chance to multiply, yet were it possible, all the descendants of a single Paramecium would at the end of five years be found to possess a volume of protoplasm approximately equal to ten thousand times the volume of the earth !

With such extraordinary tendency to over-production on the part of all living matter, it is obviously due to some efficient check upon every species of animal and plant that the numbers are kept within bounds. This is the check which Darwin and Wallace both recognized and called the *struggle for existence*.

Struggle for Existence.—The struggle for existence is the competition constantly going on between all organisms for the possession of conditions in which each may flourish.

For a plant a suitable soil, a certain degree of moisture, and sunlight are necessary. For spots presenting favourable conditions there is constantly going on a competition between individual plants of one species (*intraspecific struggle*) and between the members of different species (*interspecific struggle*). All these plants have also to struggle against the physical environment, against excess of moisture or of drought, against extreme heat or cold, and so forth (*environmental struggle*). The struggle can actually be witnessed when a small plot of ground in a garden is allowed to run to waste. A variety of weeds will soon appear, which will kill the original garden plants. Later on the more hardy weeds will be seen to kill off some of those that first appeared. Plants have not only to compete among themselves, but also to contend against their numerous animal foes. Of all the young seedlings that sprout up, a fairly large proportion are destroyed by insects, and by snails

and slugs. Cattle and goats also produce a marked effect on the vegetation of a country. It is a well-known fact that introduction of goats into certain districts has led to a gradual destruction of the forests in those parts; the seedlings are eaten as they appear, and no young trees are developed to take the place of those that go down with age.

Among animals also there is a keen struggle for existence. Everywhere, more particularly among the lower organisms, indiscriminate destruction of ova and young embryos is going on. Most lower animals produce hundreds, nay thousands of ova every year. By far the greater majority of them are destroyed indiscriminately because they fail to reach a favourable spot for their development or become the food of other animals. Young ones that are not well fitted to cope with the dangers or procure the necessary food are readily destroyed. This intraspecific struggle, that is, struggle against the animal's own kind, is the most severe check of all, for each one's needs are precisely similar, and the competition is in all points. There is also an interspecific struggle, that is, between animals of different kinds. This struggle is more severe between closely related species, because they require much the same conditions as regards food and shelter. Often enough there is a struggle between different animals, so that one may afford food to another.

Man himself is no exception to the rule. Overpopulation and want of food and space lead to internecine warfare. Man hunts down other creatures to feed himself, and sometimes falls a victim to the wild animals. He also finds a powerful foe in those tiny microscopic organisms—the germs which are responsible for causing various diseases in him. They feed on the blood or flourish in various other juices of his body, and

when the conditions are favourable for their unchecked growth, epidemics are the result. He has also to contend against his physical environment. Drought and consequent scarcity of food, extreme heat or cold, lightning and tempest, cyclones and floods, earthquakes and volcanic eruptions, all act as positive checks to population.

Variation.—Variation is the progressive factor in evolution, for without variation no change could occur and evolution would be impossible. No two organisms are precisely alike. It is a commonly observed phenomenon which everyone can verify for himself. Although the fact that variations do so commonly occur is not open to argument, the causes of variations, their character, and the extent to which an organism may vary are all subjects for debate, and these problems will be briefly discussed in the next chapter. It must be remembered, however, that although, for purposes of exact observation or record, we speak of a certain part or parts of an organism as showing a variation, it is the organism as a physiological whole that varies. The parts are intimately linked together, and what is apparently trifling variation in a particular organ may be only one of a series of changes affecting the organism as a whole.

Heredity.—Heredity means the likeness which an offspring bears to its parents, in its general organization as well as in the characters of its individual parts. It is the conservative factor in evolution, that which tends to keep the individuals of a species to their normal form; at the same time, variation having given rise to a new character, heredity causes it to persist. What kinds of variations are transmitted by heredity is one of the most debatable subjects in Biology, and the question will be considered in its proper place. Here it will suffice to mention that some variations are undoubtedly trans-

missible by heredity, and it is these which serve as the basis for evolution. Evolution is the change produced in a *race* of organisms; the mere variation of the *individual*, no matter how profound or how beneficial it may be, is not evolutional until it can be handed on to the offspring, and this is the function of heredity.

Artificial Selection.—Darwin was led to his principle of natural selection by his observations on the struggle for existence and variations. He paid considerable attention to a study of variations as they occur in domestic animals and cultivated plants. Variations are observed to take place in all directions. Man takes good care of those individuals that show particular variations and mates them with other individuals exhibiting variation in a similar direction. Other individuals are not taken good care of and are consequently weeded out. Thus man has been able to select those qualities which seemed most likely to be useful to him or those for which he otherwise took a fancy, and has thus been able to produce, from one and the same original wild stock, widely different varieties. This process whereby the various breeds or races of domestic animals and plants have been formed is called *artificial selection*.

Among the domestic animals, instances of striking differences brought about through artificial selection are met with. The domestic Dog, for example, exhibits a large number of very marked varieties. The differences between a Greyhound and a Bulldog are not merely superficial, but there are such well-marked differences in the form of the skull and in the proportion of the bones of the limbs that if they were found to occur between two wild forms, the forms would be recognized not merely as different species, but also as belonging to distinct genera. Sheep, Cattle, Pigs, and Horses all

true that sometimes it may be a mere matter of chance that some of the young ones may be preyed upon by their enemies, while others may escape; but, generally speaking, such individuals will survive as are best fitted to cope with the conditions to which they are subjected—for example, those which are fleet of foot and thus escape being pursued, or others which by their shade of colour or the nature of their markings (see pp. 615, 616), elude the observations of an enemy, or still others which, on account of possessing a somewhat thicker covering, can better withstand extremes of cold.

Gradual changes in climate and other conditions are also known to take place. Some animals or plants previously used as food might become exterminated, or a new enemy might find its way into the district inhabited by the species. "Then such individuals as presented variations which enabled them better to cope with the new surroundings would have the advantage over the others, and would have a much better chance of surviving and leaving progeny. The useful variations thus produced and transmitted to the progeny would tend to increase, generation after generation, until a form sufficiently distinct to be regarded as a new species had become developed from the original one." (Parker and Haswell.)

The effect of natural selection as an evolutionary factor has thus been summarized:

a. Under new conditions harmful characters will be eliminated by selection.
b. Beneficial characters are intensified and modified so as to be even more useful.
c. The great body of characters neither hurtful nor beneficial will not be modified, but will persist through heredity.

"The resultant of all these existing conditions (of environment) is, according to Darwin and his followers, an inevitable natural selection of individuals and of species. Thousands must die where one or ten may live to maturity (*i.e.*, to the time of producing young). Which ten of the thousand shall live depends on the slight but sufficient advantage possessed by ten individuals in the complex struggle for existence due to the fortuitous possession of fortunate congenital differences (variations). The nine hundred and ninety with unfortunate congenital variations are extinguished in the struggle and with them the opportunity for the perpetuation (by transmission to the offspring) of their particular variations. There are thus left ten to reproduce their advantageous variations. The offspring of the ten, of course, will vary in their turn, but will vary around the new and already proved advantageous parental condition : amongst the thousand, say, offspring of the original saved ten the same limitations of space and food will again work to the killing off before maturity of nine hundred and ninety, leaving the ten best equipped to reproduce. This repeated and intensive selection leads to a slow but steady and certain modification through the successive generations of the form and functions of the species; a modification always towards adaptation, towards fitness, towards a moulding of the body and its behaviour to safe conformity with external conditions. The exquisite adaptation of the parts and functions of the animal and plant as we see it every day to our infinite admiration and wonder has all come to exist through the purely mechanical, inevitable weeding out and selecting by nature (by the environmental determining of what may and may not live) through uncounted generations in unreckonable time. This is Darwin's causo-mechanical theory to explain the trans-

formation of species and the infinite variety of adaptive modification. A rigorous automatic natural selection is the essential idea in Darwinism, at least in Darwinism as it is held by the present-day followers of Darwin." (Kellogg.)

Protective Resemblance and Mimicry.—In all classes of the animal kingdom many cases are met with where the animals show remarkable resemblance with their natural surroundings. The colour of the polar bear and other animals in the arctic regions is snowy white, animals of the desert are of a dull greyish-brown colour, and many animals living in the foliage of trees are green. Not only does the general colour harmonize with the surroundings, but very often there are spots or stripes (see p. 515) to give it a pattern, and there are even modifications in shape and development of special outgrowths or appendages. These resemblances have the effect of rendering the animals inconspicuous and thus not only protecting them from their enemies, but also preventing them from being seen by their victims before the latter have come within their range. Numerous instances could be cited, but some of the most marvellous examples of protective resemblance are to be seen in some of the insects. In the Stick insect the whole body is very much like a piece of a dry twig. In the "walking-leaf" insect, the whole body (Fig. 262) is of a bright-leaf-green colour, the wings are shaped and veined like leaves, and even the body and legs

FIG. 262.—*Phyllium*, "Walking-leaf."
(From Lull, after Doflein.)

exhibit leaf-like outgrowths. In the well-known Indian leaf butterfly, *Kallima* (Fig. 263), the resemblance to a leaf is seen when the insect comes to rest among leaves. The butterfly is strikingly coloured above, and the colouring is seen in flight. On the instant of alighting, the insect practically disappears, for now the wings are folded together above the body so as to expose their protectively coloured under surface. It is now deceptively like a dry, dead leaf, and the stalk and mid-rib, veins and other markings, even down to such minute details as rust spots, are perfectly represented.

FIG. 263.—Leaf butterfly, *Kallima*, from India, in the resting condition. (From Lull, after Weismann.)

In other instances, animals bear a superficial resemblance to a member of a different group. Such cases of *mimicry* are also generally met with among the insects. A butterfly which is perfectly palatable to insectivorous birds shows resemblance to another butterfly which, on account of its nauseous taste and conspicuous warning colours and markings evolved to advertise that fact, is generally left untouched by the birds. Some flower-frequenting flies which have no sting or weapon mimic stinging bees and wasps. These phenomena of protective resemblance and mimicry are adequately explained on the theory of natural selection, and thus afford further evidence in favour of that theory.

Objections to the Theory of Natural Selection.—The operation of Natural Selection as a chief factor in Evolution is now universally admitted, but there are several weighty objections to its being regarded as the sole cause. Do small initial differences confer any real

advantage in the struggle for existence so as to bring Natural Selection into play, and would these slight differences go on adding so as to lead to the formation of perfected organs? Certain organs and cases of elaborate mimicry are of apparent advantage only in the perfected state, and natural selection acting only upon minute gradations towards perfection does seem an inadequate explanation in such cases. It is also difficult to account for the origin of co-ordinated sets of structures, such as bones, muscles, ligaments, increased blood-supply, that would be necessary, for example, to produce the huge antlers of the Irish elk. The chances of all these varying together might be regarded as infinitesimally remote. Then again these very antlers came to be developed to such an extent as to cause the organ to become actually a hindrance and not a help. Natural Selection could not, of course, have exerted any influence beyond the point of greatest usefulness. Natural Selection is held to account for the development of the power of regeneration: for example, the power to regenerate the tail possessed by many lizards. Small powers of regeneration when first developed would be perfectly useless, and if struggle for existence is really so keen as to affect the question at all, all the lizards which lost the tail would be exterminated before any regeneration took place. On these and several other grounds it is now held by many that Natural Selection is not the only factor in evolution. As Darwin himself maintained, "natural selection has been the main but not the exclusive means of modification."

De Vries' Theory of the Origin of Species by Mutation.—According to De Vries, new species arise, in a state of nature, not by the accumulation in particular directions of small, fluctuating variations, but by sudden marked changes appearing in the offspring of

a normal parent. These large changes or discontinuous variations are called *mutations.* They are not variations merely in degree or size of a single individual character, the change may take place in a number of quite distinct parts, and once such variations occur, the characters breed true, and thus new elementary species may arise in a single generation. To quote his own words, "According to the theory of mutation, species have not arisen gradually as the result of selection operating for hundreds or thousands of years, but discontinuously by sudden, however small, changes. In contradistinction to fluctuating variations which are merely of a *plus* or *minus* character, the changes which we call mutations are given off in almost every manner of new direction. They only appear from time to time, their periodicity being probably due to perfectly definite but hitherto undiscovered causes."

De Vries, as the result of a fairly extensive series of experiments on Plant breeding, came to the conclusion that selection of ordinary individual differences has no permanent effect at all, and that a better method is offered if a single plant showing definite mutations of a desired type is carefully isolated; it produces offspring like itself, and continues to breed true for an indefinite number of generations. Domestic breeds have, according to him, arisen discontinuously as definite novelties, and artificial selection started usually by taking hold of some prominent modifications on which to begin working. In the year 1886 he found a large number of specimens of the evening primrose, *Oenothera lamarckiana*, growing in a field near Amsterdam, which had probably found their way there from a neighbouring garden. He found among them two distinct new forms, each as an isolated patch, which were found to propagate themselves true to type. A number of roots and seeds were taken and

cultivated. In all 50,000 individuals were raised, and 800 of these showed among themselves as belonging to as many as fifteen quite distinct new forms, each of which breeds true and differs from the others in a number of characters, affecting their size, stems, leaves, etc. Differences were such as exist between distinct species when found in a state of nature. Thus a set of new species was supposed to have been found in the actual process of origination. Doubt has, however, been thrown upon the interpretation of these observations, as the plants were probably hybrids, and their variability may have been due to the splitting up of such hybrid characters.

The theories of mutation and natural selection are not mutually exclusive, for in whatever manner new characters arise, they would be subject to the action of natural selection in the struggle for existence. De Vries admits the action of natural selection in weeding out unsuitable mutations. But he holds the view that the struggle for existence between individuals is not a factor in evolution—that is to say, in the process of the formation of new species natural selection does not act until definite mutations have occurred. Mutations, whenever occurring, might certainly be a better and a quicker mode of species formation, as favourable mutations will be preserved by natural selection and unfavourable ones destroyed. But the occurrence of mutations could hardly account for the production of all the marvellous adaptations which exist in nature. The mutual adaptation between the position of nectaries in certain flowers and the length of the proboscis in the insects that fertilize them, the facts of protective resemblance and mimicry, and many other cases of adaptations to environment, can be much better explained as being the result of the accumulation under the influence of

natural selection of what Darwin called slow successive variations.

Isolation.—Another factor in evolution is isolation or segregation, which prevents promiscuous interbreeding. Structural modifications having been produced, isolation gives such modifications a chance to become permanent. Isolation may be geographic where, on account of physical barriers, forms showing modifications get separated from one another and tend to vary further in their respective directions. Or the forms may not be so separated, yet there may be isolation in a physiological sense. Owing to actual structural differences, mating may be a physical impossibility, or the gametes may not combine, or even if they do the resulting individual may not develop or may be sterile and unable to procreate. Sometimes, as among the different races of mankind, mental aversion may also play a part. But for isolation of some sort, new variations would be swamped, and unless they were of a dominant character (see next chapter) would disappear straight away.

CHAPTER IV

SORTS OF VARIATIONS—CAUSES OF VARIATIONS—PHYSICAL BASIS OF HEREDITY—CONTINUITY OF THE GERM-PLASM—LAWS OF HEREDITY

In the previous chapter we have taken note of the occurrence of variations and the existence of heredity as undeniable facts and as necessary factors in evolution. We did not stop to consider what are the causes of variations or what are the means by which heredity asserts itself. Variations also are not all alike, and apparently only some of them are heritable. We shall now consider therefore what different sorts of variations exist, which of them are transmissible by heredity, what may be the causes of variations, and what is known of the mechanism of heredity.

Sorts of Variations.—Variations may be classified in different ways according to the point of view from which we look at them. Thus three sets of contrasting kinds may be readily recognized.

(1) According to the nature of the change, variations are recognized as *meristic* if relating to the number of repeated parts in an organism, and are contrasted with *substantive* variations, which concern the structure (including shape, size, and colour) of the organism or its parts. As examples of the former may be mentioned the occasional occurrence of star-fish with six arms (instead of the normal five), or an increase in the number of vertebræ in any region, or the occurrence of thirteen

ribs in man instead of the normal number twelve, or development of extra digits on hand or foot as in the case of persons possessing six fingers. Examples of substantive variations are seen in the shape, size, and colour of the human body and of its various parts. The height of the individual, the shape of such features as ear, nose, and fingers, the colour of eyes and hair, are all subject to very great variation.

(2) According to the amount of the change, small *fluctuating* or *continuous* variations are contrasted with larger *discontinuous* variations or *mutations*.

Fluctuating variations are such as pass into one another by very minute or even insensible gradations, which fluctuate on either side of the mean or average condition. That is to say, any such variation will be seen to be connected with the normal type by intergrades differing very slightly from each other. If any part of an organism is examined in a sufficiently large number of individuals, as regards any particular character, fluctuations will be found to occur both in the plus as well as in the minus direction, and the largest number of individuals will show the most frequent condition, and the greater the deviation from the mean the lesser will be the number of individuals exhibiting it. These fluctuations, as mentioned before, were relied upon by Darwin as forming the material for selection. Whatever be their causes, the fact that fluctuating variations are constantly occurring in nature is sufficient to justify us in regarding such variability as a normal attribute of all organisms.

Mutations or discontinuous variations differ from fluctuating variations in their usually deviating more widely from the type of the species, and their not fluctuating about the old mean or average condition. A new position is, so to say, assumed abruptly and not

by a gradual series of steps. This new position is stable, and the characters appearing as mutations are transmissible by heredity. Mutations are not occurring always or with any definite periodicity. On the whole they are distinguished for the rarity of their occurrence. Mutations may be meristic or substantive. Human beings with six fingers or toes are occasionally met with, and many cases are on record where this meristic mutation has been transmitted by heredity. Many cases of substantive mutation are also known. One of the best known examples is that of Ancon sheep, facts concerning which were thus stated by Huxley : " It appears that one Seth Wright, the proprietor of a farm on the banks of the Charles River, in Massachusetts, possessed a flock of fifteen ewes and a ram of the ordinary kind. In the year 1791, one of the ewes presented her owner with a male lamb, differing, for no assignable reason, from its parents by a proportionally long body and short bandy legs, whence it was unable to emulate its relatives in those sportive leaps over the neighbours' fences, in which they were in the habit of indulging, much to the good farmer's vexation." The inheritance of this peculiarity was so strong that this single individual became the starting-point of a new breed. The case of mutations observed in *Oenothera lamarckiana* by De Vries himself in 1886 has already been referred to. Other known examples are thus classified by Thomson : " A hornless calf, a tailless kitten, a short-legged lamb, a thornless rose, illustrate discontinuous *quantitative* variations of a *negative* kind. Giants, ' wonder-horses,' long-tailed Japanese cocks, merino-fleeced sheep, spine-covered holly leaves illustrate discontinuous *quantitative* variations of a *positive* kind. Sometimes the novelty cannot be readily expressed in quantitative terms—an entirely new colour turns up, the variant is immune to

certain diseases to which the stock is susceptible, leaves become fasciated, a tree becomes 'weeping,' a genius is born. When a new pattern of organization or a new constitutional property turns up, we speak of a discontinuous *qualitative* variation."

"Some modern authorities go the length of saying that 'mutations' form the sole raw material of evolution, and that 'individual fluctuations' do not count at all. This seems an illustration of the common tendency to take up an extreme position in the enthusiasm of a new discovery. Because discontinuous variations are common and important it does not follow that continuous fluctuations are of no moment." (Thomson.)

(3) As regards the seat of origin, *somatogenic variations*, which affect the body of the organism and are acquired in the lifetime of the individual (hence often referred to as *acquired characters*), are contrasted with *blastogenic* or *germinal variations* which arise in consequence of some modifications in the germ-cells.

Somatogenic variations or acquired characters are impressed upon the individual during its lifetime and are due to the direct influence of environment upon the soma or body. The effects of use and disuse and the modifications artificially produced are also included under this heading. Many examples of acquired characters will readily occur to everyone. The complexion of a fair-coloured individual getting sunburnt by long residence in tropical climes, the better development of the muscles of an athlete, the effects of education, the loss of a tail or a digit through accident or otherwise, the boring of the lobe of the external ear, the small feet of Chinese ladies and the slender waists of many European women, are all familiar examples. Such characters, it is well known, are not transmitted by heredity to succeeding generations. In many other cases the variations are attributable to a

direct influence of the environment. Tower's experiments on potato beetles and Agar's observations on water-fleas have already been referred to (p. 604). In rats and mice, raising or lowering the temperature to which the young animal is exposed during its growth has been shown to bring about certain modifications in bodily structure, and such modifications appear to be inherited. In a large number of cases, mice reared in a warm room (about 21° C.) were found to differ considerably from those reared in a cold room (about 5° C.) as regards the mean length of the tail, foot, and ear, which were longer in the former than in the latter. Similar differences occurred to a marked extent in the offspring of the warm-room and cold-room parents, even when the offspring were reared together in a common room under identical temperature conditions.

Blastogenic or germinal variations are those which owe their origin to some modification in the germ-cells from which the organism exhibiting them has developed. These variations may be obvious from birth, as, for example, the colour of the iris or the hair, or be such as from their nature cannot appear until later in life, as, for example, variations in adult size and proportion. They are variations which have been, as it were, predetermined in the germ, and will manifest themselves sooner or later, at any period from the beginning of embryonic life to the death of the organism.

In any given case, it is often very difficult to decide whether a particular variation is somatogenic or blastogenic. Ordinarily acquired characters are believed to be non-inheritable, but it seems possible that somatogenic modifications occurring generation after generation, may sooner or later make an impression upon the germ-cells and thus ultimately become blastogenic. Blastogenic variations are from their very nature, as being

due to modifications in the germ-cells, handed on by heredity from generation to generation. All true mutations must be blastogenic, and many fluctuating variations may also belong to the same category.

Causes of Variations.—The causes of somatogenic variations are apparent, for these are modifications which the organism undergoes in its lifetime in response to external conditions. The influence of abundance or scarcity of food, of heat or cold, presence or absence of enemies, and the presence or absence of exacting conditions, all make themselves felt upon the indivudual in greater or less degree. In some cases these somatogenic variations can be ascribed to the *direct action* of the environment, *i.e.*, they are believed to depend on physical and chemical changes produced by external conditions. In many cases the variations are adaptive, and represent definite and apparently *purposive* responses on the part of the organism to changes in its environment. That is to say, the power of adaptation or adaptability, which is possessed in varying degree by different organisms, is also an important factor in the question.

The causes of blastogenic variations are obscure. Three principal explanations are offered for their origin and are thus summarized by Kellogg :—

(1) " That there exists in the germ-plasm an inherent tendency or capacity to vary so that there is inevitable variation in all individuals produced from the germ plasm."

(2) " That amphimixis, *i.e.*, biparental parentage, is the principal cause of variation, it seeming logical to presume that individuals produced from germ-cells derived from the fusion of germ-plasm coming from two individuals more or less unlike would differ slightly from either of the parental individuals."

(3) " That congenital variation is due to the influence of the ever-varying environment of the germ-cell-producing individuals."

Against each one of these several objections can be taken, and from the nature of the case it is not easy to prove experimentally the correctness of any of these explanations. We are still more in the dark as to the causes of those blastogenic variations which are of the nature of mutations, for in their case not only the causes of their occurrence but the causes of the rarity of their occurrence have also to be sought for.

Heredity and Environment.—Heredity is usually understood to mean the offspring showing certain character or characters originally possessed by the parent. But, as pointed out by Goodrich, Heredity obviously includes two different processes: the transmission of the factors of inheritance or *genes*, and the reappearance of characters in successive generations. Organisms are moulded as the result of the interaction of the environmental stimuli and the germinal constitution. As stated by Goodrich, " Every character is the product both of factors of inheritance and of environment, and can only be reproduced when both are present. Characters are due to responses, and have to be made anew at every generation. Only those characters reappear regularly in successive generations which depend for their development on stimuli always present in the normal environment. Others, depending on a new or occasional stimulus, do not reappear in the next generation unless the stimulus is present." From this point of view, it would be well to drop altogether the use of the expression " acquired character," and to adopt Johannsen's terms " *gene* " for a factor, " *genotype* " for the whole assemblage of factors transmitted from one generation to the next, and " *phenotype* " for the characters developed from them in a

particular environment. The same genotype may give rise to a number of different phenotypes if the environment is changed, and conversely similar phenotypes may result from different genotypes.

Physical Basis of Heredity.—Just as protoplasm is the physical basis of life itself, so the chromatin of the nuclei of the two germ-cells is now generally believed to be the physical basis of heredity from one generation to another. It was Weismann who first emphasized in 1892, by the publication of his Germ-Plasm theory, the sharp distinction between the somatic cells which, with almost endless diversity of form and function, build up the body of one of the higher plants or animals, and the germ-cells, which play little if any part in the life of the individual in which they lie secluded, but are destined, under favourable circumstances, to give rise to the new generation. What is passed from one generation to the next is only the minute sperm and the ovum. The sperm is scarcely more than a nucleus (almost completely filling the head) provided with a thin coat of cytoplasm drawn out into a tail, and the latter is very often of no consequence in the actual act of fertilization. So it is the nuclei of the germ-cells, and, as can very well be inferred from the facts of maturation and the karyokinetic division of the nucleus, it is the chromatin contained in the nuclei of the germ-cells that is the physical basis or carrier of heredity. The fixity in the number of chromosomes in the nuclei of all the cells composing the body of organisms belonging to one species, the halving of this number in the reduction division during the process of maturation of the germ-cells, and the restoration of the normal number of chromosomes in the act of fertilization, all indicate the importance of the chromosomes. It is these ids or chromosomes that, according to Weismann's theory, we conceive of as containing the

primary constituents of a complete organism. "Such ids in larger or smaller numbers make up the whole germ-plasm of a germ-cell, and each id in its turn consists of primary constituents or determinants, *i.e.*, of vital units, each of which determines the origin and development of a particular part of the organism."

It is evidently of the greatest consequence that this material basis of heredity should be equally divided between the daughter-cells. The elaborate mechanism of centrosomes and nuclear spindle, and the longitudinal splitting of each individual chromosome, bring about that result. "If, as Weismann maintains, and as has actually been demonstrated in many cases, each elongated chromosome is made up of a row of chromomeres, which may be supposed to differ from one another as to the determinants which they contain, it is obvious that longitudinal splitting is the only way in which a qualitative as opposed to a mere quantitative division of the heredity substance can be brought about."

Although what is set forth above is the more generally accepted view, some observers still maintain that cytoplasm also plays a very important part in heredity.

Continuity of the Germ-plasm.—Every fertilized ovum or zygote contains a set of paternal and a set of maternal chromosomes in its nucleus. When the zygote begins to segment, each of the daughter-cells at the first and later cleavages inherits equally the chromatic determinants originally derived from the male and the female parents. Most of the cells arising from the segmentation of the zygote become differentiated and specialized in various directions to form the complex multi-cellular body of the individual. These are the somatic cells. Others give rise to the germ-cells. The germ-cells are early established as such, and their content of chromatin

is derived from the original fertilized ovum. They are in no way the product of the body, but are direct lineal descendants of the zygote. The "body" having exhausted its powers of growth and renewal sooner or later dies, but the germ-cells conjugate and renew their power of cell-division and take on a new lease of life. Thus a direct stream of germ-plasm flows continuously from germ-cells to germ-cells through succeeding generations. According to Weismann, inherited characters are transmitted not from soma to soma, but from germ-cells to germ-cells, by virtue of the continuity of the germ-plasm. The soma has little if any influence upon the germ-cells which it contains beyond that which is involved in supplying them with protection and nourishment. There is no means of communication between the soma and the germ-cells, and consequently somatogenic characters, which are acquired in the lifetime of the individual body as the direct result of the action of the environment (or use and disuse of organs), cannot be transmitted to the germ cells and therefore cannot be inherited. Ever since Weismann promulgated this view, the isolation of the germ-plasm and our not being able to conceive any satisfactory mode in which modifications taking place in the parts of the body might affect the germ-cells have stood as an effective barrier in the way of a belief in the possibility of the inheritance of acquired characters.

Laws of Heredity.—As a result of a vast amount of statistical study and a great deal of experimental work, a few definite laws of inheritance have been worked out, with which, under certain conditions, organisms seem to conform. The chief among these are Galton's Laws and Mendel's Laws.

Galton's Laws.—Galton based his generalization on data as to stature and other qualities in man and as

to coat-colour in Basset hounds. His law is as follows: "The two parents between them contribute *on the average* one-half of each inherited faculty, each of them contributing one-quarter of it; the four grandparents one-quarter, or each of them one-sixteenth; and so on the sum of the series $\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \ldots$ being equal to 1 or the total inheritance of the organism." Thus an inheritance is not merely biparental, but through the parents it is multiple, and the *average* contributions made by grandparents, great-grandparents, etc., are definite, and diminish in a precise ratio according to the remoteness of the ancestors.

Closely connected with Galton's Law of Inheritance is another important generalization known as the Law of Filial Regression, which also we owe to him. According to the first, *on an average* the individual derives half its characteristics from its immediate parents and the remaining half from its more remote ancestry. If the immediate parents, or one of them, differ markedly from the average condition of the race in any particular character, the offspring will have a tendency to inherit the particular character, but not to the same extent, for the influence of the grandparents and other ancestors will tend to counteract that of the parents and cause a partial return—or regression—towards mediocrity. In the words of Karl Pearson, "It is the heavy weight of this mediocre ancestry which causes the son of an exceptional father to regress towards the general population mean; it is the balance of this sturdy commonplaceness which enables the son of a degenerate father to escape the whole burden of the parental ill."

Mendel's Laws.—What is now known as Mendelism was first discovered by an Austrian monk, Gregor Johann Mendel. He carried out an extensive series of experiments in the seclusion of his monastery garden on the

numerous garden varieties of the common edible pea (*Pisum sativum*) and published his results in 1865 and 1869 in the proceedings of a local natural history society, where they remained buried and unnoticed for more than thirty years. Long after Mendel's death, his conclusions were independently rediscovered in 1900 simultaneously by De Vries, Correns, and Tschermak, and it speaks highly for their chivalry that "honouring the all-but-forgotten monk, they called the new-found law Mendel's, rather than their own" (Castle). Bateson discovered that the law applies to animals as well.

Mendel was the first to emphasize that in questions of heredity we must deal with individual characters singly. The inheritance consists, in part at least, of "unit-characters" which are typically continued as such or not at all, and behave as if they were distinct units which can be shuffled about and distributed to the offspring, to some degree independently of each other. In studying the different varieties of pea, he was able to fix upon seven pairs of contrasting characters. To mention only three of these: (1) the plants may be tall or dwarf; (2) the form of the ripe seed may be, roughly speaking, either round and smooth *or* angular and wrinkled; (3) the colour of the seed-contents or cotyledons which usually determine the colour of the seed as a whole may be some shade of yellow or more or less intense green.

Having defined the differentiating characters, Mendel made crosses between these, investigating one character at a time. Thus, pollen from a pea of the round-seeded variety was transferred to the stigma of a pea of the angular-seeded variety, self-fertilization being prevented in the latter by the removal of the stamens before they were ripe. This was the method pursued in all his experimental investigations. In the hybrid or cross-bred

offspring it was found that they showed *one* of each pair of contrasted characters to the total, or almost total, exclusion of the other. It is either one or the other, and no intermediate forms appear. Mendel called the character that prevailed *dominant*, and the character that was suppressed, or apparently suppressed, *recessive*. The first big result established was that crosses between a plant with a dominant character and a plant with a recessive character yield offspring all resembling the dominant parent as regards the character in question.

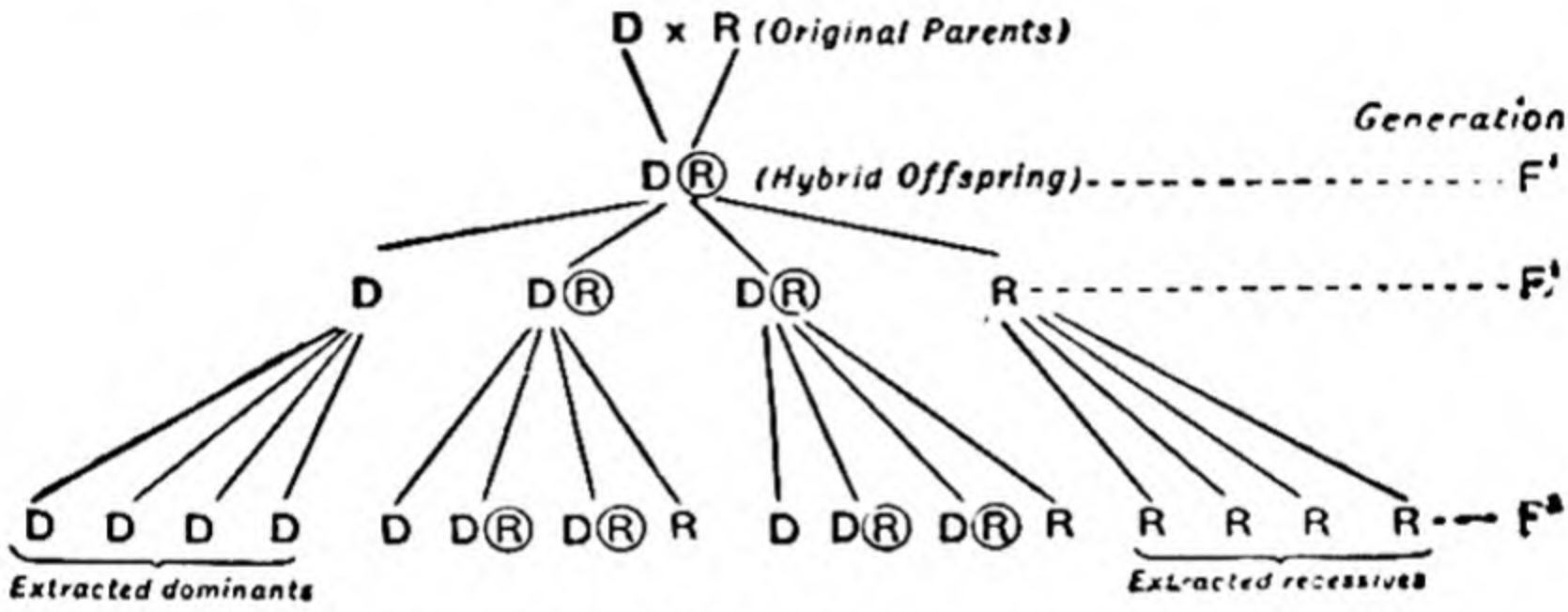


FIG. 264.—Chart illustrating Mendelian phenomena. (After Dendy.)

This generalization may be called *the Law of Dominance*, and symbolically expressed as

$$D \times R = D\,(R).$$

In the next generation these cross-bred plants (products of D and R, or R and D, but all apparently like D) were allowed to fertilize themselves (Fig. 264, F^1), and the result was that their offspring exhibited both the original forms, the proportion of individual plants possessing the dominant character being with considerable regularity *in the ratio of three to one* (F^2). Thus in one case, when tall and dwarf plants were crossed, out of 1064 plants, 787 were tall and 277 dwarfs.

These were again self-fertilized and the offspring (seed) of each sown separately. The recessives gave rise to recessives only in any number of succeeding generations (F^3). The offspring of the dominant were not all alike; they gave, firstly, pure dominants which, like the recessives, bred true and gave rise to pure dominants indefinitely, and, secondly, others which, while *appearing* dominant, nevertheless contained recessive characters hidden in them (F^3), and when self-fertilized produced once more dominants and recessives in the ratio of three to one.

The general results may be expressed as in the diagram on previous page.

The explanation given by Mendel for the phenomena noted above is very simple and ingenious. In a hybrid only one of the contrasting characters appears, but in the germ-cells of this hybrid the two parental characters are both present, though only one in any one germ-cell. This generalization may be called *the law of splitting or segregation*, and affords a suitable explanation of the observed ratio between the numbers of dominants and recessives. Each male gamete and each female gamete will carry only one of the contrasting characters. And if on the average the number of male and female gametes bearing either character were about equal, then by miscellaneous and random mating (mating according to the law of probabilities) we should get

$DR \times DR$ . . . (F_1 hybrids self-fertilized)

DD	DR	DR	RR

all appearing as dominant

or 3 D : 1 R.

Let us now mention a few cases from among animals

which illustrate Mendelian inheritance. If a grey house-mouse is crossed with a white mouse, the offspring are all grey. Thus it is found that grey is dominant, white recessive. The grey hybrids are inbred; their offspring are grey or white in the proportion of three to one. If these white are inbred they produce whites only for subsequent generations, and thus prove themselves "pure." But when the grey are inbred they are found

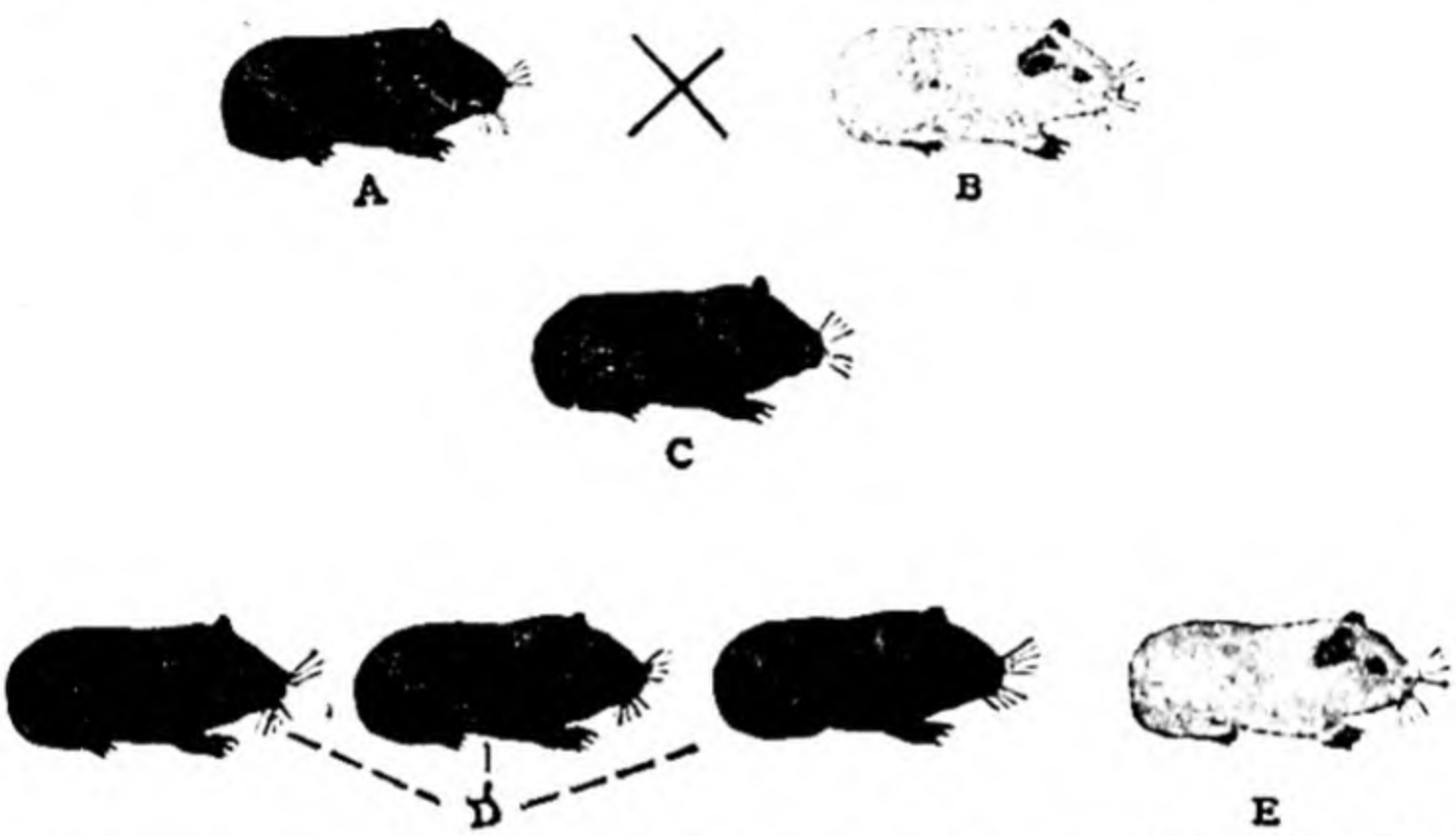


FIG. 265.—Mendelian inheritance in Guinea-pigs. A black animal A, mated with an albino B, produces progeny which are all black like C. These progeny have albinism in a recessive state, and when they are mated produce blacks, D, and albinos, E, in the ratio of three to one. (After Holmes.)

to be of two kinds; one-third of them produce only greys, which go on producing greys, while the other two-thirds though outwardly the same, produce both greys and whites. Castle has experimented with guinea-pigs and found that black or white colour, long or short hair, rough or smooth coat are contrasting characters. In mating those of contrasting colours, black is found to be dominant and white recessive. Fig. 266 illustrates the segregation of germ-cells, say in the case of black and white guinea-pigs.

Working with combinations of two characters, the results obtained are similar, although naturally more complicated. When gametes are produced, factors for producing contrasting characters segregate, but the assortment of one pair of characters is independent of every other pair of characters. There is recombination

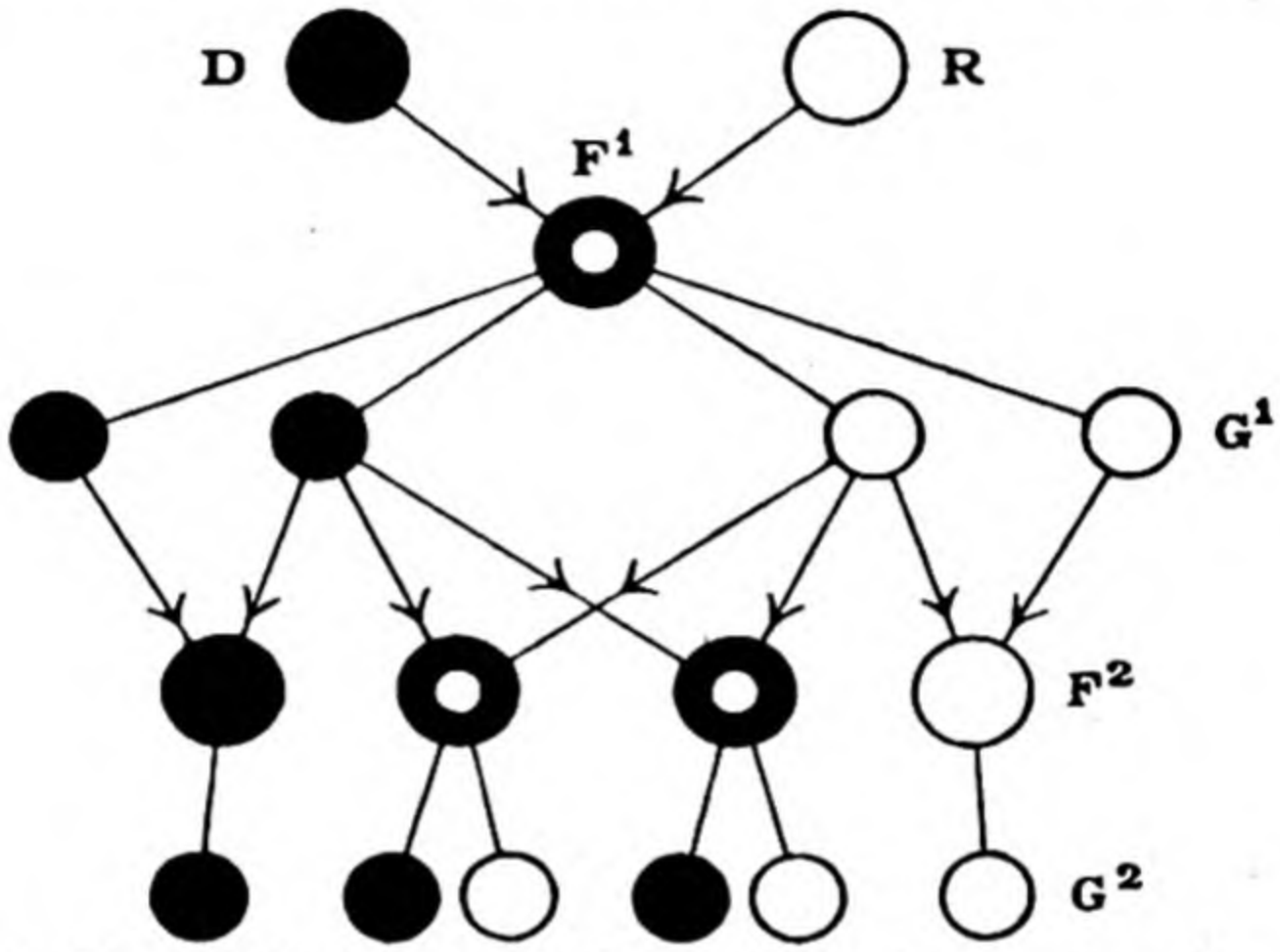


FIG. 266.—Diagram illustrating Mendelian segregation of germ-cells. (After Thomson.)

D. dominant parent; R. recessive parent; F^1. hybrid offspring, the recessive character latent; G^1. germ-cells of F^1, supposed to be segregated in two camps, each bearing the potentiality of either dominant (black) or recessive (white) character. The arrows indicate possibilities of fertilization, F^2. Two "blacks" may combine, producing pure dominant offspring—to the left. Two "whites" may combine, producing pure recessive offspring—to the right. Black and white may combine as at the start, yielding impure dominants—black enclosing white. G^2. this line indicates the kind of germ-cells produced by the second generation, F^2.

of characters, but for each pair of characters taken separately the results are in accordance with Mendel's law of segregation.

It must be noted, however, that the *complete* dominance which Mendel observed or which is found in the case of experiments with mice or guinea-pigs is not always to be found. An interesting case is that of the blue

Andalusian fowl. It is a well-known breed, but it has long been known that this kind of fowl cannot be made to breed true. When one blue Andalusian is crossed with another, it is found that of the offspring only about half the number are blue, one-quarter are black, and one-

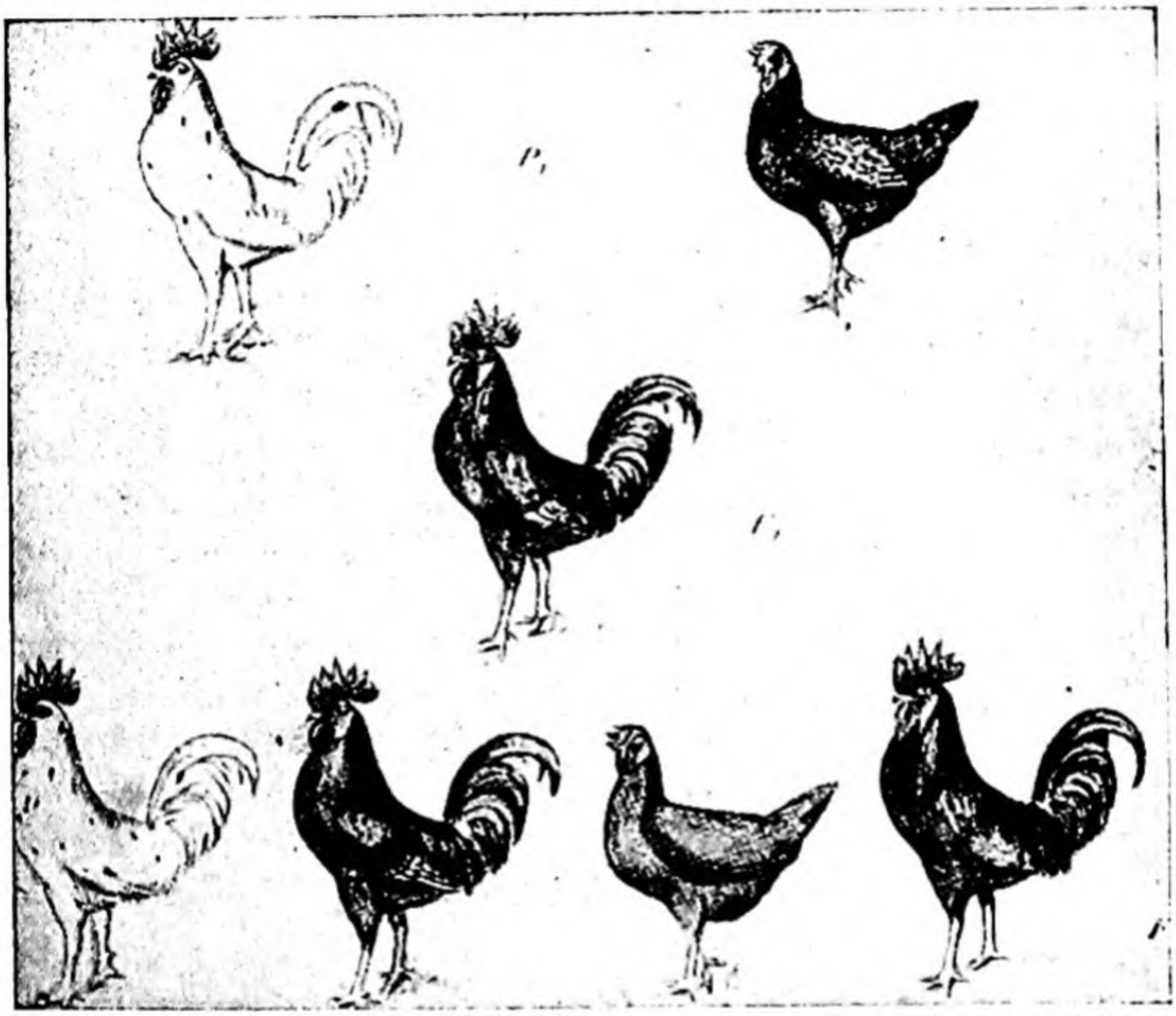


FIG. 267.—Cross between splashed white and black fowls, giving in F_1 blue Andalusian. If F_1 is crossed with F_1, one splashed white, to two blues, to one black are produced in F_2 generation. (After Morgan.)

quarter white. Thus the blue Andalusian is a hybrid, and the so-called " wasters " are the parent forms. If a black is mated with a white, the result is a blue Andalusian again. But why the hybrid is blue is not clearly understood. Other experimenters have worked with various other animals and plants and found practically

the same results. There are some difficulties and not a few discrepancies, but, as Bateson says, "The truth of the law enunciated by Mendel is now established for a large number of cases of most dissimilar characters." Mendel's law is a generalization of the greatest importance, but it must be remembered that it does not apply universally to all cases of inheritance.

Cytological Basis of Mendelism.—Morgan has shown that the behaviour of chromosomes at the time of maturation of the eggs and the sperm-cells furnishes an adequate explanation of Mendel's laws of heredity. The hereditary factors or genes are located in the chromosomes. As stated in a previous chapter, in an ordinary cell-division every chromosome splits longitudinally into two exactly similar halves, one of which goes to each of the two nuclei. In this process every gene is split, and each nucleus not only carries the same number and kinds of chromosomes, but a full complement of genes is contained in those chromosomes. In the nuclei of the somatic cells there are two sets of homologous chromosomes, one set being originally derived through the sperm from the male parent and the other through the ovum from the female parent. Assuming that in a particular case there are four chromosomes in the nucleus of each gamete, and designating them by different letters, there will be a paternal set A, B, C, D, and a maternal set of similar chromosomes *a*, *b*, *c*, *d*. Thus in the nuclei of the somatic cells the chromosomes will be in pairs, viz., A*a*, B*b*, C*c*, D*d*, and there will be two genes for every heritable character situated in opposite members of the same chromosome pair.

In the reduction division during gametogenesis, members of each pair of chromosomes place themselves side by side, and later segregate, one from each pair going to the opposite pole. Thus there will be segrega-

tion of homologous chromosomes, and each gametic nucleus will contain either A or *a*, B or *b*, C or *c*, and D or *d*, and correspondingly the genes contained in them will also be assorted. So far as any pair of genes is concerned, any particular gamete will contain either the paternal or the maternal gene and not both, and of a pair of allelomorphic characters either one or the other will be transmitted by a gamete, *i.e.*, it will carry either the dominant or the recessive character.

During fertilization the genes for the dominant and recessive characters of each pair will be brought together, and the F_1 hybrid will show the dominant character. When this hybrid produces gametes, an equal number of gametes will carry the gene for the dominant or the recessive character, and chance mating will give the three to one ratio in the F_2 (Fig. 264). The genes located in a second pair of chromosomes B*b*, will be assorted independently of the genes contained in the chromosomes A*a*. This is the reason why in the cases of combinations of two or more characters, the assortment of one pair of characters is independent of another pair of characters.

In the nuclei of the cells of the fruit fly *Drosophila melanogaster*, on which Morgan and his colleagues have made their studies, there are only four pairs of chromosomes, but there are hundreds of allelomorphic characters. They have shown that genes for many characters are located in one and the same chromosome, and such characters remain linked, that is, tend to be transmitted together. Linked genes may, however, cross over from one chromosome of a pair to its mate by exchange of corresponding portions of the chromosomes when they are intimately associated together in the early stages of the reduction division.

Applied Mendelism.—By the practical application

of Mendelism it has been found possible to breed plants or animals with special characters in view, and also to combine three or more desired characters in a plant or an animal from as many different varieties of ancestors. In America spineless cactuses and hornless cattle have been raised, and the desirable characters fixed to breed true by hybridization and careful selection. In India also a certain measure of success has been gained in the direction of increasing the yield of crops, by bringing together in one type the good qualities of a number of types. By way of example, we may refer to the improved types of sugar-cane and wheat. The Coimbatore sugar-cane gives a higher yield of sugar, and certain types of wheat selected and bred at Pusa not only combine high yield, good milling and baking quality, strong straw, and resistance to rust, but are also able to mature with less water than ordinary wheats. The pedigree herd of Sahiwal cows is another example of the successful results of careful selection and breeding. In this breed, the yield of milk per cow which used to be only 5 lb. per day in 1914, is now 21 lb. per day.

INDEX

A

Abdomen, abdominal cavity, 18, 331, 350, 439, 464, 471
Abiogenesis, 245
Acetabulum, 49, 459
Aciculum, 325
Acoustic spots, 170
Acquired characters, 624; inheritance of, 630
Acrania, 586
Acromion, 456
Adamsia, 290
Adaptation, 201
Adenoids (lymphatic glands), 465, 472
Adrenal bodies, 96, 128, 499
Air-bladder, 415
Air-cavities, 431
Alary muscle, 353
Albumen, of bird's egg, 534
Alimentary canal, see Enteric canal
Alisphenoid, see Skull
Allantois, 577, 578
Alligators, 427
Alternation of generations, 288
Alveoli of jaws, 467
Amino-acids, 72
Amnion, 575, 577
Amœba: occurrence and general characters, 203; movements, 205; resting condition, 206; nutrition, 207; growth, 208; excretion, 209; respiration, 209; metabolism, 209; reproduction, 210; immortality, 210; conjugation, 211; death, 211
Amœboid movements, 99, 205
Amphibia, 196, 406, 419, 424, 437
Amphioxus, 408
Ampulla, of semicircular canals, 170
Anabolism, 132
Anal cerci, 350
Anal Cirri, 326
Anal segment, 294, 326
Anal styles, 350
Analogous, analogy, 192
Anatomical evidence for evolution, 585
Anatomy, 192
Angular process of mandible, 450
Animals and Plants, comparison of, 222
Ankle, see Tarsus
Anopheles, 249; life-history, 362
Anopheles, as a career of malarial parasites, 253; Anopheles and Culex compared, 362
Ant-eaters, 510
Antelopes, 511
Antenna, 336, 345, 346
Antennule, 337
Anura, 195
Anus, 7, 232, 239, 294, 326, 341, 352, 385, 411, 429, 440, 472
Anthozoa, 289
Anthropoidea, 522
Ants, 379
Aorta, aortic arches, see Arteries
Aperture, or apertures (see also Foramen, and under Nephridium, Kidney, Pores, Reproductive organs, &c.); auditory, *Rabbit*, 440, 446, 496; cloacal, see anus: exhalant and inhalant, 381, 385
Apes, 524
Aphis, 376, 542
Appendages, lateral, and their skeleton: *Frog*, 6, 27, 31, 46, 50; *Prawn*, 333; *Cockroach*, 345, 348; *Dogfish*, 415; *Bony fish*, 414, 418; *Bird*, 432; *Rabbit*, 456, 460; development of, in Vertebrates, 574
Appendicularia, 408
Apricot chalcid, 369
Aptera, 374
Aqueous chamber and humour, 165
Arachnida, 379
Arachnoid fluid, 137
Archenteron, 545
Area opaca, 551
Area pellucida, 551
Area vasculosa, 553
Arm, see Fore-limb
Armadillos, 510
Arterial arches, 76, 420, 425, 435, 480, 568
Arteries: *Frog*, 25, 76; *Prawn*, 339; *Mussel*, 390; *Fish*, 420; *Rabbit*, 481; Vertebrate embryo, 568
Arthropoda, 197, 329, 371
Articular membrane, 332
Articular processes, see Zygapophyses
Artificial selection, 610
Artiodactyla, 517
Arytenoid cartilage, 125, 474
Ascaris, 402
Ascidian, 407
Asexual generation, see Agamobium
Asexual reproduction, see Fission, Budding, Spore
Assimilation, 132, 208, 271

Astacus, 372
Aster, 531
Asterias, 404
Astragalus, 50, 461
Atlas vertebra, 452
Atrial pore, 409
Atrium, 409, 410
Atrophy, see Vestige
Auditory capsule, 34, 37, 418, 445
Auditory organ (*incl.* statocyst): *Frog*, 43, 168; *Rabbit*, 496; development of, in Vertebrates, 563
Auditory ossicles, 446, 497
Auricle, see Heart
Aurelia, 289
Automatism, see Movements
Aves, 196, 427
Axial fibre: of Vorticella, 239; of Carchesium, 244
Axial parts, 4
Axis fibre, see Naurexis
Axis vertebra, 452

B

Baboons, 511, 522
Backbone, see Vertebral column
Bacteria, 135
Balanatidium, 235
Balanoglossus, 407
Bandicoots, 508
Barbules, 429
Barnacle, 371
Basi-occipital, see Skull
Basi-sphenoid, see Skull
Bats, 511, 521
Bears, 511
Beavers, 511
Bed-bugs, 376
Bees, 366, 379
Beetles, 376
Bell of medusæ, see Umbrella
Bilateral symmetry, 261
Bile, 67, 131
Bile-duct, 67, 473
Bile-passages, 120
Binomial nomenclature, 190
Biogenesis, 245
Biology, 1
Bird, development of, 550 *et seq.*
Birds, see Aves
Bladder, see Gall-bladder and Urinary bladder
Blastocœle, see Segmentation-cavity
Blastocyst, see Blastodermic vesicle
Blastoderm, 544, 551
,, embryonic and extra-embryonic portions, 553, 574
Blastodermic vesicle, 554
Blastomere, 545
Blastopore, 180, 322, 547, 549, 550
Blastostyle, 275, 279
Blastula, 545
Blind spot, 165, 495
Blood: *Frog*, 18, 74, 82, 97; *Earthworm*, 305, 309; *Cockroach*, 354; *Lancelet*, 409; *Fish*, 420; *Bird*, 435; *Rabbit*, 437, 486
Blood-corpuscles: colourless, see Leucocytes; red, 97, 435, 486
Blood-sinus, see Sinus
Blood-vessels: *Frog*, 76; *Earthworm*, 305; *Prawn*, 339; *Cockroach*, 353; *Mussel*, 390; *Fish*, 420; *Rabbit*, 480
Body-cavity, see Cœlome
Body of vertebra, see Vertebra
Body-segments, see Metamere
Boll-worms, 369
Bone: replacing and investing, 41, 443; nature of, 51; microscopical structure of, 109
Bones, see Endoskeleton, Skull, Vertebra, Ribs, Sternum, and under individual bones
BONY FISH: General characters, 412; locomotor organs, 415; skeleton, 416; digestive organs, 420; respiratory organs, 420; circulatory organs, 420; nervous system, 420
Bony fishes, 422
Botany, 1
Bot-fly, 376
Brachial plexus, see Nerve-plexus
Brachionus, 403
Brain: *Frog*, 26, 139, 182; *Earthworm*, 314; *Prawn*, 342; *Cockroach*, 355; *Lancelet*, 409; *Pigeon*, 435; *Rabbit*, 487; development of, in Vertebrates, 558
Brain-case, see Skull
Branchia, see Gill
Branchial apertures, arches, clefts, and septa: *Tadpole*, 183, 186; *Lancelet*, 409; *Dogfish*, 415, 418; *Bony fish*, 417; development of, 565
Branchial filaments, 420
Branchial vessels: *Fish*, 420; *Tadpole*, 420
Breast-bone, see Sternum
Bronchus, 475
Buccal cavity, 14, 303, 351, 465
Bud, budding, 272, 275
Bufo, Bufonidæ, 194, 195
Bugs, 376
Bulb, see Medulla oblongata
Bulbus aorta, 86
Bulbus aortæ, see Heart, Frog
Bulla, tympanic, 446
Butterflies, 377

C

Cæcum, 472
Cænosarc, 277
Calcaneum, 50, 461
Calcar, 50
Calotes, 423
Camel, 511; fore-limb, 519
Canal: central, of spinal cord, 138; neural, see Vertebral column; neu-

renteric, 183; radial and circular of Medusa, 281; semicircular, of ear, see Auditory organ and Membranous labyrinth; vertebrarterial, 452
Canaliculi, see Bone
Cancer, 373
Canine teeth, 467
Capillaries, 92
Capitular facet and capitulum, 452, 454
Carapace, 331
Carbohydrates, 68
Carbon dioxide, 62
Carchesium, 244
Cardo, 348
Carinatæ, 436
Carotid arch, see Arteries of Frog, Dogfish, and Rabbit
Carps, 412, 415
Carpus, 48, 458
Cartilage, 18, 30, 108, 412, 418, 441; calcified, 44, 46
Cartilaginous fishes, 422
Caruncle, 578
Castings of earthworm, 292
Cat-fish, 412
Caterpillar, 365
Cats, 511, 515
Cauda equina, 146
Cavum aorticum, see Heart, Frog
Cavum pulmo-cutaneum, see Heart, Frog
Cell, 103, 205, 526; and see under various types
Cell-colony, see Colony
Cell-differentiation, see Differentiation, and under development of various types
Cell-division, 99, 528
Cell-membrane or wall, 206, 222, 225, 527
Cellulose, 222, 225
Cement, 468
Centipede, 329, 371
Centrale, 458, 461
Centrolecithal ova, 543
Centrosome, 527, 536, 540
Centrosphere, 527
Centrum, see Vertebra
Cephalochorda, 406, 408
Cephalopoda, 395
Cephalothorax, 330
Cere, 428
Cerebellum: *Frog*, 139; *Pigeon*, 435; *Rabbit*, 490; development of, 558
Cerebral flexure, 560
Cerebral ganglion, see Brain
Cerebral hemispheres: *Frog*, 142; *Pigeon*, 435; *Rabbit*, 487; development of, 558
Cerebral nerves, see Nerves
Cerebral vesicles, 182, 558
Cerebro-pleural ganglion, 386 (Fig. 153)
Cervical groove, 331
Cetacea, 511, 515
Chætopoda, 323, 327
Chalaza, 534 (Fig. 231)
Change of function, 498
Chaos, see Amœba
Chela, 335
Cheliceræ, 379
Cheliped, 335
Chiasma, optic, 140, 488
Chick, see Bird
Chimpanzee, 524
Chiroptera, 511, 521
Chitin, 206, 294, 331
Chlorophyll, 224
Chordata, 406
Chorion, 581
Choroid, 165, 495
Choroid fissure, 561
Choroid plexus, 141, 488
Chromatin, 116, 205, 215, 526
Chromosomes, 529, 535, 538
Chrysalis, 365
Cilia and ciliary movement, 103, 230, 235, 238
Ciliary folds, muscles, nerves, and vessels, 166, 494, 495
Ciliata, Ciliate Infusoria, 227, 245
Circulation of blood, 82, 87, 305, 338, 353, 390, 420, 435, 477
Circulatory organs, see Blood-vessels and Lymphatic system
Cirri, 325, 326, 409
Clasper, 415
Class, 196, 197
Classification, 192, 197, 198, 397
Clavicle, 46, 432, 456
Clitellum, 296
Clitoris, 505
Cloaca, 21, 435
Cloacal aperture, see Anus
Clypeus, 346
Cnemial crest, 461
Cnidoblast, 268
Cnidocil, 268
Coagulation of blood, 74, 100
Cochineal, 368
Cochlea, 169, 498
Cockroach: general characters, 346; head, 346; mouth-appendages, 347; thorax, 348; legs, 348; wings, 349; abdomen, 350; abdominal appendages, 350; digestive organs, 351; circulatory organs, 353; respiratory organs, 354; excretory organs, 355; nervous system, 355; reproductive organs, 357
Cocoon, 296, 359
Codling moth, 369
Cœca, hepatic, 352
Cœlenterata, 260, 288
Cœlomata, 291
Cœlome, 18, 182, 291, 297, 384, 410, 463; development of, 182, 548, 556; extra-embryonic, 577
Cœlomic epithelium, 299; and see Ephithelium and Germinal Epithelium

Cœlomic fluid, 302
Coleoptera, 376
Colon, 471
Colony, Colonial organisms, 244
Columba, see Pigeon
Columella, 44, 171
Commissures, see Blood-vessels and Nervous system; of brain, 140, 491
Common fowl, skeleton of, 431
Condyle, occipital, see Skull
Cones of retina, 167
Conjugation, 177, 211, 220, 233, 242, 252, 274, 535, 541; and see under development of various types
Conjunctiva, 164
Connectives, 315, 342, 355, 392
Connective-tissue, 16, 106
Contour feathers, see Feathers
Contractility, nature of, 105
Conus arteriosus, 86, 421, 478
Copromonas, 221
Coracoid, 46, 425, 432
Coracoid process, 456
Coral, 291
Cornea, 164, 356, 495
Coronoid process, 450
Corpus adiposum, see Fat-body; callosum, 488; cavernosum and spongiosum, 502; striatum, 491
Corpuscles, see Blood-corpuscles and Leucocytes
Cortex of brain, 142, 488
Cortical layer, 229, 235, 236
Coverts, see Feathers
Cowries, 393
Coxa, 348
Crabs, 371
Cranium, see Skull
Crayfish, 371
Creation, 198
Cribriform plate, 445
Cricket, 374
Cricoid cartilage, 474
Crocodiles, 424, 427
Crop, 351, 433
Cross-fertilization, 321
Crura cerebri, 139, 489, 558
Crustacea, 262, 330, 371
Crystalline lens, see Lens of Eye
Ctenidium, 381, 385, 394
Culex, 253; life history of, 360; Culex and Anopheles compared, 362
Cutaneous glands: *Frog*, 116; *Rabbit*, 438
Cuticle: in unicellular animals, 230, 238; in multicellular animals, 279, 294, 329
Cuttle-fishes, 395
Cyprinidæ, 412
Cyst, see Cell-wall and Encystation
Cystic duct, see Bile-duct
Cytopharynx, 230
Cytoplasm, 526
Cytostome, 230

D

Daphnia, 372
Darwinian theory, 605
Dasyures, 508
Daughter-cells and nuclei, 528
Death, 12, 135, 210
Decidua, 581
Decomposition, 12, 135; and see Putrefaction
Deer, 511; fore-limb of, 519 (Fig. 224)
Dendron, 151
Dental formula, 468
Denticles (Nereis), 326
Dentine, 468
Deric epithelium, see Epidermis
Dermal scales, 415
Dermal teeth, 415
Dermis, 114, 439 (Fig. 186)
Descent, doctrine of, see Evolution
Development, meaning of the term, 10, 241. For development of the various multicellular types, see under their names
De Vries' Mutation theory, 617
Dialyser, 69
Diaphragm, 464
Diastema, 465
Diastole of heart, 89; of contractile vacuole, 231
Diencephalon, 141, 488, 558
Differentiation, 184, 185, 227, 259
Diffusion, 69, 305
Digestion, 70, 208; intra- and extra-cellular, 270, 271, 305
Digestive glands, see Digestion, Enteric canal, Liver, Glands, Pancreas
Digestive system, see Enteric canal
Digits, 7, 49, 429, 458, 462
Diphycercal tail, 423
Diploblastic, 264, 277
Diploid chromosome, 542
Dipnoi, 411, 423
Diptera, 376
Disc of Vorticella, 238
Discoid segmentation, 551
Dispersal, 241
Distal, 7
Distribution of food-materials, 133
Divergence of character, 199
Division of physiological labour, 185, 259
Dog, 511; skull of, 512
Dogfish: General characters, 415; exoskeleton, 415; endoskeleton, 418; blood-system, 420
Dolphins, 511
Dominant, 633
Dorsal, 7
Down feathers, see Feathers
Dragon-flies, 374
Drum-membrane, see Tympanic membrane
Duck-billed Mole, 507
Ductless glands, 95

Ducts, see under names of individual ducts and glands
Ductus arteriosus, 483
Dugongs, 511
Duodenum, 20, 471; and see Enteric canal
Dura mater, 137

E

Ear, see Auditory organ; internal, middle, and external, 446, 496, 563
EARTHWORM: habits, 292; general characters, 293; metameric segmentation, 294; cœlome and enteric canal, 297, 299, 301; cell-layers, 299; blood-system, 305; respiration, 309; nephridia, 310; nervous system, 314, differentiation of organs and tissues, 317; reproduction and reproductive organs, 318; development, 322
Ecdysis, 360
Echinodermata, 404
Ect-ethmoids, see Skull of Fish
Ectoderm, 180, 189, 263, 275, 281, 322, 547, 551
Ectoplasm, 205, 229
Edentata, 510
Efferent duct of spermary, 173, 320, 502, 572
Effodientia, 510
Egestion, 207
Egg of hen, 534
Egg-cell, see Ovum
Ejaculatory duct, 357
Elasmobranchii, 412, 422
Elephants, 511, 517
Elytra, see Cockroach, wings
Embryo, 10, 178; and see under various types
Embryological evidence for Evolution, 590
Embryology, 192
Embryonic area, 553
Embryonic membranes, 574
Emu, 436
Emulsification of fats, 71
Enamel, 468
Encystation, 206, 213, 217, 242, 254, 255
Endoderm, 180, 189, 263, 269, 275, 281, 322, 547, 551
Endoderm-lamella, 281, 284
Endolymph, 170
Endoparasite, see Parasite
Endoplasm, 205, 229
Endopodite, 334
Endoskeleton: *Frog*, 14, 31, 184; *Lancelet*, 408; *Dogfish*, 418; *Bony fish*, 416; *Fowl*, 431; *Rabbit*, 440; development of, in Vertebrates, 573
Energy, conversion of potential into kinetic, 209; source of, in chlorophyll-containing organisms, 223
Entamoeba, 212
Enteric canal: *Frog*, 20, 183; *Earthworm*, 297, 303; *Prawn*, 341; *Cockroach*, 351; *Mussel*, 385; *Lancelet*, 409; *Fish*, 420; *Pigeon*, 433; *Rabbit*, 465-473; development of, in Vertebrates, 183, 188, 565
Enteric epithelium, see Epithelium
Enterocœle, 548
Entero-kinase, 72
Enteronephric, 312
Enteron or enteric cavity, 261, 263, 275, 281, 297, 341, 351, 547, 563
Enteropneusts, 406
Entomology, importance of, 370
Epencephalon, 558
Epiblast, see Ectoderm and p. 548
Epicoracoid, 45
Epicranium, 346
Epidermis: *Frog*, 114; *Earthworm*, 294, 299; *Lancelet*, 409; *Fish*, 415; *Bird*, 429; *Rabbit*, 438
Epididymis, 502, 572
Epiglottis, 469, 474
Epiphysis, 451, 459
Epipodite, 335
Epistylis, 244
Epithelialcells: columnar, 101; ciliated, 103; glandular, 116 *et seq.*; squamous, 101; stratified, 114
Epithelium, 101, 285; cœlomic, 299 (and see Peritoneum); deric—see Epidermis; enteric, 299 (and see Endoderm)
Equilibration, organ of, see Auditory organ
Erepsin, 72
Euglena: occurrence and general characters, 214; movements, 215; structure, 215; nutrition, 217; resting stage, 217; reproduction, 217; animal or plant, 222
Eustachian tube or recess, 15, 171, 446, 469, 496
Eustachian valve, 480
Eutheria, 510
Eutyphœus, 292
Evolution: evidence for evolution, 585; meaning of, 584; organic evolution, 199; theories of, 602
Excretion, 131, 133, 209
Excretory organs, see Kidney and Nephridium, and compare Contractile vacuole
Ex-occipital, see Skull
Exopodite, 334, 348
Exoskeleton: cuticular, 279, 331, 345, 382; dermal, 415, 426; epidermal, 429, 438
Expiration, 126
Extra-cellular digestion, 208, 271
Eye: *Frog*, 5, 163; *Nereis*, 324; *Prawn*, 333; *Cockroach*, 346, 356; *Rabbit*, 440, 494; development in Vertebrates, 561
Eye: compound, 333

Eyelids, 5, 440
Eye-muscles, see Muscles of eye
Eye-stalks, 333, 337

F

Fabellæ, 460
Fæces, 9
Family, 195
Fascia, 16, 56
Fasciola, 399
Fat-body, 23, 351
Fats, 68
Feathers, varieties of, 430
Femur, 50, 432, 460
Fenestra ovalis, 44, 171, 446, 497
Fenestra rotunda, 446, 498
Fenestræ, of Cockroach, 347
Ferment, fermentation: amylolytic, 70; peptonising or proteolytic, 70
Fertilization, 176, 535, 541; and see also Conjugation, and under development of various types
Fibrin, 100
Fibula, 50, 460
Filoplumes, see Feathers
Filum terminale, 137, 491
Fingers, see Digits
Fin-rays, 410, 412, 418
Fins: *Tadpole*, 186; *Lancelet*, 409; *Bony fish*, 412
Fishes, see Pisces
Fission, 99, 178, 210, 233, 241; multiple, 211, 233, 251, 254
Fissures of spinal cord, 137
Flagellata, 214, 258
Flagella, 214, 269
Flat-worms, 398
Flea, 376, 377
Flocculus, 446, 490
Flying foxes, 511
Fœtus, 505
Follicle, ovarian, 175, 503
Fontanelle, 41, 418
Foods, 63, 67, 69
Foot, of molluscs, 381, 383; and see Pes
Foramen: lacrymal, 447; intervertebral, 33, 451; magnum, 35, 441; obturator, 460; of Monro, 142, 490
Foramina for cerebral nerves, see Skull
Fore-brain, 182, 558
Fore-gut, 342, 351
Fore-limb or fin, see Appendages
Fornix, 491
Fossa ovalis, 478
Fossils, 593
Fox, 515
Frog: Preliminary account, 4; mouth-cavity, 14; skin and muscles, 16; body-cavity and its contents, 18; neural cavity and its contents, 25; structure of limbs, 27; skeleton, 30; joints, 52; muscles, 54; alimentary canal and digestion, 64; vascular system, 74; circulation of blood, 87; lymphatic system, 94; simple tissues, 97; compound tissues and glands, 113; lungs and larynx, 124; kidneys, 128; structure and functions of nervous system, 132; sense-organs, 161; reproductive organs, 173; fertilization of eggs, 10, 177; development, 10, 178, 549; metamorphosis, 12, 186; classification, 192
Frontal, see Skull
Fronto-parietal, see Skull, Frog
Fruit-flies, 369
Function, see Physiology

G

Galea, 348
Gall-bladder, 20, 65, 473
Gallus, see Common Fowl
Galton's laws, 630
Gamete, 177, 211, 233, 242, 253, 322, 359, 537, 541
Gametocyte, 252, 253, 535
Gametogenesis, 535
Ganglion, 146, 151; and see Nerve-ganglia
Gastric glands, see Glands
Gastric juice, 70, 73, 118
Gastrocnemius, 56
Gastropoda, 395
Gastrula, 545, 550
Gemmation, see Budding
Genæ, 346
Generation, alternation of, see Alternation of generations
Generation, asexual, 288
Generation, sexual, 288
Generative organs, see Reproductive organs
Genital papilla, 296
Genus, 190, 194
Geological eras and epochs, 620
Geological record, imperfection of, 597
Germ-cells, see Sex-cells
Germ-plasm, 542; continuity of, 629
Germinal disc, 550
Germinal epithelium, 174, 175, 318, 503
Germinal vesicle and spots, 533
Gestation, 505
Giant-fibres, 315
Gibbons, 524
Gill-arches and clefts, see Branchial apertures, arches, clefts and septa
Gill-cover, 187, 331, 337
Gill-rays, see Branchial rays
Gills: *Tadpole*, 12, 183, 186; *Prawn*, 337; *Mussel*, 385; *Fish*, 411, 417
Giraffes, 511
Gizzard: *Earthworm*, 304; *Cockroach*, 351
Gland-cells: Hydra, 268, 269; Earthworm, 304; and see Glands and Goblet-cells

Glands: accessory, 321; colleterial, 359; conglobate, 357; Cowper's, 502; cutaneous, 116, 438; digestive, see Enteric canal; gastric, 118, 471; Harderian, 168, 496; lacrymal, 496; mammary, 437, 439, 463; Meibomian, 496; mushroom-shaped, 357; perineal, 440, 502; prostate, 502; racemose, 120; rectal, 502; salivary, 468; sebaceous, 438; spermiducal, 321; and see Kidney, Liver, Pancreas, etc.
Glands, ductless, 95, 465
Glenoid cavity, 46, 456
Glomerulus, 129, 569
Glottis, 15, 469
Glycogen, 122
Gnat, life-history, 360
Goats, 511
Goblet-cells, 103, 118
Gonad, 173; and see Reproductive organs
Gonaduct, see Reproductive organs
Gonapophyses, 350
Gonotheca, 277
Gorilla, 524
Grantia, 398
Grass-hoppers, 374
Grey matter of spinal cord and brain, 138, 142, 151
Growth, 210
Gryllotalpa, 536
Gullet, 20, 230, 238; and see Enteric canal
Gymnophiona, 196

H

Hæmocœle, 341, 351
Hæmoglobin, 100, 309
Hairs, 437, 438
Hallux, 461
Hand, see Manus
Haploid chromosomes, 537
Harderian gland, 168, 496
Hares, 511
Head, 4, 324, 333, 346, 414, 428, 438
Head-fold and process, 557
Heart, 18, 75, 83, 338, 353, 390, 420, 424, 435, 477; development of, 567; pulsation of, 87
Heat, evolution of, 135
Hedgehogs, 510
Helodrilus, 292
Hemichorda, 406
Hemiptera, 376
Hepatic cæca, 352
Hepatic ducts, see Bile-duct
Hepatic portal system, see Portal system
Heredity, 609; physical basis of, 628; laws of, 630
Hermaphrodite, 272, 318
Hermit-crabs, 371
Herrings, 412
Heterocercal tail, 415
Hibernation, 9
Higher (triploblastic) animals, uniformity in general structure, 300
Hind-brain, 182, 489
Hind-gut, 342, 352
Hind-limb or Fin, see Appendages
Hip-girdle, see Pelvic arch
Hippocampus, 490
Hippopotami, 511
Hirudinaria, 328
Hirudinea, 327
Hirudo, 328
Histology, 97
Holoblastic segmentation, 544
Holophytic nutrition, 217, 224, 226
Holozoic nutrition, 217, 224, 226
Homocercal tail, 422
Homology and homologous, 192, 284
Homology, serial, 34, 51, 294, 337
Honey-bee, life-history, 367
Hook-worms, 20
Hormones, 96
Horse, 511; ancestry of, 600; fore-limb of, 518 (Fig. 223c)
Host, 248, 249, 251
House flies, 376; life-history of house-fly, 364
Humerus, 46, 433, 457
Hybrids, 191
HYDRA: occurrence and general characters, 260; species, 261; movements, 262; mode of feeding, 262; microscopic structure, 263; digestion, 270; asexual, artificial, and sexual reproduction, 271; development, 274
Hydranth, 275
Hydroid polypes, 274
Hydrotheca, 277
Hydrozoa, 288
Hyoid, 30, 42, 450
Hymenoptera, 378
Hyoid arch, 418
Hypoblast, see Endoderm and p. 548
Hypobranchial groove, see Endostyle
Hypostome, 260, 275, 282
Hyraxes, 511

I

Ileum, 20; and see Enteric cana
Ilium, 50, 460
Imago, 360, 366
Immortality, 210
Impregnation, see Fertilization
Incisors, 467
Income and expenditure, 132, 209, 225
Incubation, 551
Incus, see Auditory ossicles
Individual, 197, 198
Individuation, 245, 271
Infundibulum, of brain, 141, 488, 558; of lung, 475
Infusoria, 227
Ingesta and egesta, balance of, 210
Ingestion ,9, 207

Inguinal canal, 502
Inhalent pores, 397
Innominate bone, 50, 459
Insect products, 366, 368
Insecta, 330, 344, 372
Insectivora, 510
Insects, destructive, 368
Insertion of muscle, 57
Inspiration, 126
Integument, structure of, 114; and see under various types
Integumentary sense-organs, 412
Intercellular substance, 108, 112
Interstitial cells, 264
Intervertebral discs, 450
Intervertebral foramina, see Foramen
Intestinal cæca, 304, 433
Intestine, 20; see its various subdivisions and Enteric canal
Intracellular digestion, 208, 270
Invagination, 545
Iris, 5, 164
Irritability, 57, 153, 206, 239, 285
Ischium, 50, 460
Isolation, 620

J

Jackal, 515
Jacobson's organ, 494
Jaws, 14, 326, 347, 416, 418, 424, 431, 447
Jelly-fish, see Aurelia
Joints, 52, 329, 333
Jugal, see Skull

K

Kallima or leaf-butterfly, 616
Kangaroos, 509
Karyokinesis, 529
Katabolism, 132
Kidney: *Frog*, 24, 128; *Mussel*, 388 (Fig. 153); *Fish*, 421; *Pigeon*, 435; *Rabbit*, 499; development of, in Vertebrates, 569
King-crabs, 379
Kiwi, 436, 590

L

Labeo, see Bony-fish
Labial palp, 348
Labrum, 346
Lacinia, 348
Lac-insect, 368
Lacrymal, see Skull
Lacrymal glands, 168, 496
Lacteal, 95
Lacunæ, see Bone and Cartilage
Lamarckian theory, 602
Lamellæ and laminæ of gills (Mussel), 385, 386 (Fig. 153)
Lamellibranchiata, 394
Lamina terminalis, 491 (Fig. 208)
LANCELET: general characters, 408; development, 545
Larva, 11, 186, 327, 344, 360, 364, 365
Laryngo-tracheal chamber, 124
Larynx, 124, 463, 474
Laverania, see Malarial parasites
Leaf-insect, 374, 375
Leech, 328
Legs, see Appendages
Lemuroidea, 522
Lemurs, 511, 522
Lens of eye, 165, 495
Leopard, 515; protective markings of, 515
Lepas, 372
Lepidoptera, 377
LEPUS, see Rabbit
Leucocyte, 98, 302, 354, 486
Lice, 376
Life, origin of, 245; and see Biogenesis
Life-history, 10, 186; and see under various types
Ligaments, 52, 54
Ligula, 348
Limbs, see Appendages
Limnæa, 399
Lingua, 351
Linin, 528
Lion, 515; protective coloration of, 515
Lips, 440, 465
Lithite, 283
Lithocyst, 283
Liver, 18, 65, 120, 130, 184, 409, 473, 565
Liver-fluke, 399 (Figs. 160, 161)
Lizards, 426
Lobster, 371
Locusts, 369
LUMBRICUS, 311
Lungs, 12, 20, 124, 184, 187, 424, 433, 475, 567
Lymph, 16
Lymph-glands, 303
Lymph-hearts, 95
Lymphatic glands, see Adenoids
Lymphatic system, 16, 94, 486

M

Macaques, 522
Macrogamete, 242, 253
Macronucleus, 230, 234, 238, 242
Macrozooid, 242
MALARIAL PARASITES: occurrence and varieties, 249; schizogony, 249; conjugation, 252; sporogony, 253; history of discovery, 255
Malleus, see Auditory ossicles
Malpighian capsule, 129, 499, 571
Malpighian tubules, 355
Mammalia, 196, 411, 437, 506, 507, 553, 578
Mammary glands, see Glands
Man, 511, 521, 524
Manatees, 511
Mandible, 14, 42, 336, 347, 416, 426, 432, 450, 498
Mandibular arch, 416

Mantle, 380, 383, 386 (Fig. 153), 394
Manubrium: of Medusa, 280; of sternum, 455
Manus, 6, 48, 439, 458
Marginal sense-organs, see Lithocyst
Marrow-cavity, 47
Matrix, see Inter-cellular substance
Maturation of ovum, 538
Maxilla: Prawn, 336; cockroach, 348; see Jaws
Maxillary palp, 348
Maxilliped, 335
May-flies, 374
Meckel's cartilage, 42
Mediastinum, 475
Medulla oblongata, 139, 489, 558
Medullary cord, folds, groove, and plate, 181, 547, 556; sheath, 150; substance of Protozoa, 229, 238
Medusa, medusa-buds, 275, 279
Megalecithal ova, 543
Meibomian glands, 496
Melanin, 255
Membranous labyrinth, 168, 498, 563
Mendelism, 631
Mento-meckelian, see Skull, frog
Mentum, 348
Meroblastic segmentation, 544
Merozoite, 251
Mesencephalon, see Mid-brain
Mesenteron, 352, 549; and see Enteron
Mesentery, 20, 25, 472
Mesethmoid, see Skull
Mesoblast, see Mesoderm and p. 548
Mesoderm, 181, 182, 189, 322, 551; vertebral and lateral plates of, 556
Mesodermal segments, 556
Mesogloea, 263, 277, 281, 284
Mesonephros and mesonephric duct, 569
Meso-thorax, 348
Metabolism, 132, 209
Metacarpus, 48, 458
Metacromion, 456
Metagenesis, 288
Metamere, Metameric segmentation, 294, 330
Metamorphosis, 12, 189, 241, 327, 344; and see Larva
Metanephros and metanephric duct, 571
Metatarsus, 50, 461
Metatheria, 507, 508
Meta-thorax, 348
Metazoa, 259
Metencephalon, see Medulla oblongata
Mice, 511
Microgamete, 242, 253
Microlecithal ova, 543
Micromillimetre (μ) = $\frac{1}{1000}$ of a millimetre, or $\frac{1}{25000}$ of an inch
Micronucleus, 230, 238
Micropyle, 541
Microzooid, 242
Mid-brain, 182, 488, 558
Mid-gut, 352
Milk-glands, see Glands
Milk-teeth, 467
Millipede, 371
Milt, see Spermatic substance
Mimicry, 615
Mites, 379
Mitosis, 529
Molars, 467
Moles, 510
Mollusca, 197, 380, 393, 394
Monkeys, 511, 521, 522
Morphology, 192
Morula, see Polyplast
Mosquito, 249, 252, 253, 260, 376
Moths, 364, 377
Moult, 360, 431
Mouth, 5, 14, 230, 238, 260, 278, 281, 294, 325, 341, 347, 385, 414, 440
Mouth-cavity, see Buccal cavity
Movement, spontaneous, voluntary, and involuntary, 8, 13, 104, 155, 206, 285, 293, 337, 381, 415, 424, 431, and see under various types
Mucous membrane, 15
Mud-fishes, 200, 411, 423
Mule, see Hybrid, 191
Mullerian duct, 572
Multinucleate, 106, 235
Muscle-fibres: striped, 105; unstriped, 104, 118, 119; and see under various types
Muscle-plate, 556
Muscle-processes, 264, 269, 277, 284
Muscles: *Frog*, 16, 54, 56, 60, 182; *Obelia*, 277; *Earthworm*, 299; *Rabbit*, 462; and see Myomere
Muscles: of eye, 168, 496; of middle ear, 497
Muscles, papillary, 479
Muscular contraction, 57, 105, 239
Muscular impressions on shell, 383
Muscular layers of enteric canal, 66, 73, 118, 119
Muscular system, see under various types; development of, in Vertebrates, 182, 556, 572
Muscularis mucosæ, 119
Mussel: general characters, 380; shell, 382; food-current, 381; gills, 385; muscles, 383; alimentary canal, 385; nephridia, 388; blood-system, 390; nervous system, 391; sense-organs, 392; gonads, 393
Mutation theory, 617
Myomere, 182, 409, 556
Myophan striations, 230
Myriopoda, 330, 371

N

Nasal, see Skull
Nasal organ, see Olfactory organ
Naso-lacrymal duct, 168
Naso-palatine canals, see Canals
Naso-pharynx, 469
Natural History, 2

Natural selection, 612; objections to theory of, 616
Nautili, 395
Nautilus, 395
Navel, 583
Navicular bone, 461
Neck, 429, 438
Nematocyst, 266, 275, 283
Nematoda, 401
Nephridiopore, 313
Nephridium, 129, 311, 409, 410, 569
Nephrostome, 311
NEREIS: occurrence and general characters, 323; parapods and setæ, 324–325; sense-organs, 327; trochosphere larva, 327
Nerve-cells, 151, 268, 285, 315
Nerve-collar, 315
Nerve-cord, ventral, 314, 342, 355
Nerve-fibres, 151
Nerve-foramina, 449; and see Skull and Vertebral column
Nerve-ganglia, 146, 147, 148, 151, 314, 342, 355, 356, 391, 392, 560
Nerve-plexus: brachial, 143, 492; cœliac, 494; sciatic or lumbosacral, 143, 492
Nerve-roots, 146, 492
Nerves: afferent and efferent, 149, 159; cerebral, 146, 492, 560; of lateral line, 412; motor and sensory, 145, 154; phrenic, 492; sciatic, 59, 145, 492; spinal, 142, 492; sympathetic, 145, 493; vasomotor, 158; visceral, 356
Nervous impulse, 59, 136
Nervous system: *Frog*, 136; *Hydra*, 268; *Obelia*, 285; *Earthworm*, 314; *Prawn*, 342; *Cockroach*, 355; *Lancelet*, 409; *Fish*, 420; *Pigeon*, 435; *Rabbit*, 487; development of, in Vertebrates, 557
Neural arch, spine, and canal, see Vertebra
Neural cord and plate, see Medullary cord
Neural crest, 560
Neuraxon, 151
Neurenteric canal, see Canal
Neurocœle, 406; and see Canal, central of spinal cord, and Ventricles of brain
Neuroglia, 151
Neurolemma, 150
Neuron, see Nerve-cells
Neuropod, 325
Neuroptera, 374
Newt, see Triton
Nictitating membrane, 5, 428, 440
Nodes of nerve-fibre, 150
Nose, see Olfactory organ
Nostrils, 5, 15, 162, 414, 428, 440, 494
Notochord, 182, 406, 407, 409, 548
Notopod, 325
Nuclear division, 529; indirect and direct, 529, 532
Nuclear membrane, 528; spindle, 529
Nucleolus, 103; and see under Nucleus
Nucleoplasm, 528
Nucleus, 99 *et seq.*, 115, 205, 215, 221, 230, 233, 235, 238, 251, 252, 526, 528, 533, 535
Nucleus, conjugation-, 233, 242; segmentation-, 541
Nutrition, 63; and see under various types
Nyctotherus, 235

O

OBELIA: occurrence and genera characters, 274; microscopic structure, 275; structure of medusa, 279; nervous system, 285; lithocysts, 283; reproduction and development, 286; alternation of generations, 287
Occipital condyle, see Skull
Odontoid process, 452
Œnothera, 618
Œsophagus, see Gullet
Olecranon, 48, 457
Olfactory capsule, 34, 38, 446
Olfactory lobe, 142, 488
Olfactory organs: *Frog*, 162; *Rabbit*, 494; development of, in Vertebrates, 560
Olfactory pit, 410
Oligochæta, 323, 327
Omosternum, 46
Oniscus, 372
Ontogeny, 200
Oogenesis, 175, 537
Ookinete, 253
Oosperm, 177, 541; and see under various types
Oosperm, holoblastic and meroblastic, 544
Opalina, 235
Operculum, 414
Opossums, 508
Optic chiasma, see Chiasma; cup, 561; lobe, 139, 488, 558; thalamus, 141, 488; vesicle, 561
Oral cavity, see Buccal cavity
Oral hood, 410
Orang-utan, 524
Orbit, see Skull
Orbito-sphenoid, see Skull
Order, 195
Organ, 28, 134, 259, 317
Organism, 205
Origin: of muscle, 57; of species, 199, 605
Ornithorhynchus, 508
Orthoptera, 374
Oscula, 397
Osmosis, 69
Ossicles, auditory, see Auditory ossicles
Ostia: of heart, 353
Ostrich, 436
Otoliths, 170
Otters, 511

Ovary: *Frog*, 23, 175, 176; *Rabbit*, 502; and see Reproductive organs
Oviduct, 23, 176, 318, 344, 358, 435, 504, 572
Ovum, 175, 532; and see under various types
Ovum: microlecithal, megalecithal, centrolecithal, and telolecithal, 543
Oxen, 511
Oxidation of protoplasm, 132, 224
Oxyuris, 402
Oysters, 393, 394

P

Pagurus, 373
Palæmon, see Prawn
Palæontological evidence for evolution, 593
Palæontology, 593
Palate, 448, 465
Palatine, see Skull
Palatoquadrate, 41, 418
Palp: Nereis, 324; Prawn, 336; Cockroach, 348
Pancreas, 20, 67, 120, 473, 565
Pancreatic juice, 67, 70
Panther, 515
Papillæ of tongue, 162, 466
Parachordal cartilages, 573
Paraglossa, 348
PARAMECIUM: form, 228; structure, 229; mode of feeding, 231; reproduction, 233; conjugation, 233
Parapod, 324
Parasite, parasitism, 20, 212, 221, 235, 248, 249
Parasphenoid, see Skull, Frog
Parietal, see Skull
Parietal layer of peritoneum, 25, 300; see also Mesoderm
Parthenogenesis, 542
Pectoral arch, 18, 31, 44, 418, 456, 574
Pectoral fin or limb, see Appendages
Pectoralis major, 433
Pectoralis minor, 433
Pedal ganglion, 392
Pedipalpi, 379
Pelecypoda, 394
Pelvic arch, 18, 31, 49, 420, 459, 574
Pelvic fin or limb, see Appendages
Pelvis of kidney, 499
Penis, 440, 502
Penœus, see Prawn
Pepsin, peptone, 70
Pericardial sinus, 338, 353
Pericardium, 18, 477
Perichondrium, 52
Perilymph, 171
Perinæum, 440, 502
Periosteum, 52
PERIPLANETA, see Cockroach
Perisarc, 277
Perissodactyla, 517
Peristaltic movements, 72
Peristome, 238
Peristomial groove, 228
Peristomium, 294, 324
Peritoneum, 21, 25, 465
Periwinkle, 395
Pes, 6, 50, 439, 461
Peyer's patches, 472
Phalangers, 508
Phalanges, 48, 50, 458, 461
Pharyngeal mass, 304
Pharynx, 15, 304, 409, 420, 469, 565
PHERETIMA, see Earthworm
Photosynthesis, 223
Phylogeny, 200
Phylum, 196
Physiology, 1, 192
Phytomastigina, 221
Pia mater, 137
Pig, 511; fore-limb of, 519
PIGEON: domestic breeds of, 427, 612 (Fig. 261); external characters, 428; feathers, 429; skeleton, 431; muscular system, 433; digestive organs, 433; respiratory organs, 433; circulatory organs, 435; excretory organs, 435; reproductive organs, 435; nervous system, 435
Pigment cells, 115
Pigment-layer of retina, 167
Pineal body, 141, 488
Pineal eye, 141, 559 (Fig. 239)
Pinna, 437
Pisces, 196; general characters of, 411
Pisiform bone, 458
Pituitary body, 141, 488
Placenta, 505, 578
Placoid scales, 415
Plant-bugs, 376
Plant-lice, 376
Planula, 287
Plasma, 97
PLASMODIUM, see Malarial parasites
Plastic products, 225
Platyhelminthes, 398
Pleopod, 333
Pleura, pleural membrane, 465, 475
Pleuron, Prawn, 332
Podical plates, 350
Podomere, 331
Polar cells, 538
Pollex, 459
Polychæta, 323, 327
Polymorphic, polymorphism, 284
Polype, 260, 275
Polyplast, 274, 545; and see under various types
Pons Varolii, 490
Porcupines, 511
Pores, dorsal, 296
Porifera, 397
Porpoises, 511
Portal system: hepatic, 82, 421; renal, 81, 421
Post-axial and pre-axial borders of limb, 456, 460, 461

Poupart's ligament, 463
PRAWN: general characters, 330; limited number and concrescence of metameres, 330; exoskeleton, 331; appendages, 333; movements, 337; respiration, 337; reproduction, 344
Prementum, 348
Premolars, 468
Prepuce, 440
Pre-sphenoid, see Skull
Primates, 511, 521
Primitive streak and groove, 549, 550
Proamnion, 553, 557, 575
Proboscidea, 511
Proboscis, 326; of elephant, 518
Processes of skull, 443 *et seq.*
Procœlous, 31
Proctodæum, 183, 342, 351, 565
Pronation, 456
Pronephric duct, 569
Pronephros, 569
Pronucleus, male and female, 540, 541
Pro-otic, see Skull
Prosencephalon, 487, 558
Prostate, see Gland
Prostomium, 294, 324
Protective resemblance, 615
Proteins, 68
Proteus, 195, 202
Prothorax, 348
Protococcus, 222
Protoplasm, 99, 526; and see Cell
Protopodite, 334, 348
Prototheria, 507
Protovertebra, 556
Protozoa, 203, 258
Proventriculus, 433
Proximal, 7
Pseudopod, 99, 205, 211, 269
Pterygoid, see Skull
Ptyalin, 71, 469
Pubis, 50, 432, 460
Pulmonary artery and vein, see Arteries and Veins
Pupa, 360, 361, 365
Pupil, 5, 164
Pygostyle, 432
Pylangium, see Heart, Frog
Pyloric division and valve, of stomach, see Stomach
Pyramid of kidney, 499

Q

Quadrato-jugal, see Skull
Quills, see Feathers

R

Rabbit: general characters, 438; skeleton, 440; muscles and body-wall, 462; cœlome, 463; digestive organs, 465; respiratory and vocal organs, 473; circulatory organs, 477; nervous system, 487; sense-organs, 494; urino-genital organs, 499; development, 505, 553
Racemose gland, 120
Radial canals, see Canal
Radial symmetry, 261
Radio-ulna, 48
Radius, 48, 432, 457
Radula, 395, 396
Rana cyanophlyctis, 191, 193
Rana esculenta, 190, 191
Rana temporaria, 190, 191
RANA TIGRINA, see Frog
Ranidæ, 195
Ratitæ, 436
Rats, 511
Recapitulation theory, 200
Receptors, 316
Recessive, 633
Rectal gland, 502
Rectum, 21; and see Enteric canal
Reducing division, 537, 538
Reflex action, 152, 286
Regeneration, 272, 317
Renal portal system, see Portal system
Replacement of organs, 189
Reproduction, 10; and see under various types, and also Asexual reproduction
Reproductive organs, 21, 23, 173, 271, 286, 318, 344, 357, 393, 409, 435, 501, 571
Reptilia, 196, 411, 423
Respiration, 124, 127, 209, 309, 337, 354, 385, 411, 433, 473
Respiratory movements, 9, 125, 355, 477
Respiratory tube, 361
Retina, 165, 166, 495 (Fig. 209)
Retinula, 357
Rhabdome, 356
Rhinencephalon, 558
Rhinoceros, 511; fore-limb of, 518 (Fig. 223)
Rhizopoda, see Sarcodina
Ribs, 432, 454
Rocks, sedimentary and stratified, 593
Rodentia, 511, 519
Rods and cones, 167
Rostellum 401 (Fig. 162)
Rostrum, 333
Rotifera, 402
Round-worms, 401
Rudiment, often used for Vestige (*q.v.*)
Ruminants, 511

S

Sacculus, 169
Sacculus rotundus, 472
Sacred Langur, 522
Sacrum, 33, 454
Salamander, 195
Salivary glands, see Glands
Salivary receptacles, 353
San Jose scale, 369

Saprophytic nutrition, 217
Sarcodina, 203, 211, 258
Sarcolemma, 106
Scales, 414, 415
Scaly ant-eater, 510
Scaphognathite, 336
Scapula, 45, 432, 456
Schizocœle, 556
Schizogony, 249
Sclerite, 348
Sclerotic, 163, 494
Scolex, 401 (Fig. 162)
Scoliodon, 412, 413
Scolopendra, 373
Scorpion, 329, 379
Scrotal sac, 440, 501
Scyllium, see Dogfish
Scyphistoma, 289
Scyphozoa, 289
Sea-anemone, 291
Sea-cows, 511
Sea-cucumbers, 405
Sea-squirt, 407
Sea-urchins, 405
Seals, 511
Sebaceous glands, see Glands
Secretion, 116
Segment, see Metamere, Podomere
Segmentation-cavity, 180, 545, 549, 550
Segmentation of oosperm, 178, 180, 274, 287, 322, 541, 543, 544
Segmentation, equal and unequal, 544; discoid, 544
,, superficial, 544
,, metameric, see Metamere
,, -nucleus, 541
Selection, natural and artificial, 612, 610
Self-fertilization, 321
Seminal funnel, 320
,, vesicle, 320
Sense-organs and cells, 161, 283, 316, 327, 342, 356, 392, 412, 436, 494, 560
Septa, of earthworm, 301
Septum: lucidum, 491; nasal, 38, 447; interorbital, 441
Serous membrane of embryo, 577
Serpula, 327
Sesamoid bones, 458, 460
Seta, 294, 325
Sex-cells, primitive, 535, 537
Sexual characters, external, 8, 334, 415, 440
Sexual generation, 288
Sexual organs, see Reproductive organs
Sexual reproduction, see under various types
Shank, 6
Sheep, 511
Shell, 382
Shell of egg, 534
Ship-barnacle, 372
Shoulder-girdle, see Pectoral arch
Shrews, 510
Silk Moth, life-history, 364
Siluridæ, 414
Silver-fish, 374
Sinus: blood-, 353; lymph-, 16, 25; venosus, 76, 86, 420, 435, 478
Siphon, inhalant and exhalant, 381
Siren, 195
Sirenia, 511
Skeleton, see Endo- and Exo-skeleton
Skin, see Integument
Skull: *Frog*, 14, 30, 34; *Dogfish*, 418; *Bony-fish*, 416; *Fowl*, 431; *Rabbit*, 441; development of, 573
Sloths, 510
Slugs, 395
Smell, organ of, see Olfactory organ
Snails, 395
Snakes, 424, 426
Snout, 5
Somatic layer of mesoderm, 548
Somatopleure, 548
Spawn, 10
Species, 190 *et seq.*; origin of, 190, 605
Sperm, or Spermatozooid, 174, 537; and see under various types
Spermary, 23, 173, 174; and see Reproductive organs
Spermatheca, 318
Spermatic substance, 10
Spermatogenesis, 174, 535
Spermiduct, 173, 320, 344, 357, 502, 572
Sphærella, 222
Sphenethmoid, see Skull, Frog
Sphincter, 66
Spicules, 398
Spiders, 379
Spinal cord, 26, 137, 491, 560
Spindle, nuclear, 529
Spiny ant-eater, 507
Spiracle, 415
Spiral valve, 472
Spireme, 529
Spirogyra, 222
Splanchnic layer of mesoderm, 548
Splanchnopleure, 548
Spleen, 21, 95, 473
Sponges, 397
Spongin, 398
Spontaneous generation, see Abiogenesis
Spores, 243, 253
Sporogony, 253
Sporozoa, 248, 257, 258
Sporozoite, 249, 255
Spring-tails, 374
Squamosal, see Skull
Squid, 395
Squirrels, 511
Stalk of Vorticella, 236, 239
Stapedial plate, 44, 171
Stapes, 446, 497
Starch, 68, 222, 225
Starfishes, 404
Statocyst, 283
Sterilised infusions, 247
Sternebræ, 455
Sternum, 14, 46, 332, 348, 431, 439, 455
Stick-insects, 374, 615

Stigmata, 351
Stimulus, various kinds of, 59
Stipes, 348
Stock, see Colony
Stomach, 20, 65, 420, 433, 471
Stomodæum, 183, 342, 351, 565
Stratified rocks, 594
Struggle for existence, 607
Stylopyga, see Cockroach
Sub-mentum, 348
Submucosa, 117
Substitution of organs, 189
Sucker, 183, 399
Sugar-cane borers, 369
Superficial or peripheral segmentation, 544
Supination, 456
Supporting lamella, see Mesogloea
Supra-occipital, see Skull
Survival of the fittest, 605
Suspensorium, 35
Sutures, 49, 441
Swimmeret, see Pleopod
Symbiosis, 269
Sympathetic, see Nerves
Symphysis, 450, 459
Synangium, see Heart, Frog
Synovial capsule, 53
Syrinx, 435
Systemic arch, 76, 420, 480
Systole: of heart, 87; of contractile vacuole, 231

T

Tactile organs, 161, 317, 327, 356, 494
Tadpole, 11, 186 *et seq.*
Tænia, 400
Tail, 10, 188, 414, 438, 440
Tape-worms, 399
Tapirs, 511; fore-limb of, 518 (Fig. 223)
Tarso-metatarsus, 432
Tarsus, 50, 461
Tarsus, of Cockroach, 348
Taste-organs, 162, 466, 494
Teats, 439, 463
Teeth, 17, 415, 424, 431, 467
Teleostei, 412, 422
Telolecithal ova, 543
Telson, 332
Tendon, 56
Tentacles, 261, 275, 281, 324
Tergum, 332, 348
Testis-sacs, 320
Testis, see Spermary
Tetrad, 535
Thalamencephalon, see Diencephalon
Thigh, 6
Thoracic duct, 486
Thorax, 331, 348, 439, 464
Thread-cell, see Nematocyst
Thread-worm, 401
Thymus, 96, 465, 477
Thyroid, 95, 477
Thyroid, cartilage, 474
Tibia, 50, 460
Tibia, of Cockroach, 348
Tibio-fibula, 50
Tibio-tarsus, 432
Ticks, 379
Tiger, 515; protective markings of, 515
Tissues, enumeration of, 29
Toad, see Bufo
Toes, see Digits
Tongue, 9, 15, 465
Tonsil, 465
Tortoises, 424, 427
Trabeculæ cranii, 573
Trachea, 463, 474
Tracheæ, 354
Transverse process, see Vertebra
Trichina, 402
Trichocyst, 233
Trimorphic, 284
Triploblastic, 277, 291 301
Triton, 194
Trochanter, 348, 460
Trochlea, 457
Trophozoite, 251
Truncus arteriosus, see Heart, Frog
Trunk, 4, 414, 428, 438
Trypanosoma, 222
Trypsin, 70
Tubercle, and Tubercular facet, 451, 454
Tuberosity, 457, 460
Turbinals, 447, 494
Turtles, 424, 427
Tympanic cavity, membrane, and ring, 6, 43, 171, 496
Typhlosole, 305

U

Ulna, 48, 432, 457
Umbilical cord and umbilicus, 582, 583
Umbrella of Medusa, 280
Ungulata, 511, 516
Unicellular, 259
Unstratified rocks, 595
Urachus, 583
Urea, 62, 130
Ureter, 24; and see under various types
Urethra, see Urinogenital canal
Uric acid, 62
Urinary bladder, 21, 131, 499, 577
Urinary tubules, see Nephridium
Urine, 9, 62, 131
Urinogenital aperture, 437
,, canal, 502
,, duct, 173, 571
,, organs, 173, 435, 499
,, organs, development of, 569
Urochorda, 406, 407
Urodela, 195, 202
Uropod, 335
Urostyle, 30, 34
Uterine crypts, 581

Uterus, 504
,, masculinus, 502
Utriculus, 169

V

Vacuole: contractile, 206, 215, 230, 238; food-, 207, 231, 239
Vagina, 504
Valve: of Vieussens, 489, 491 (Figs. 207, 208); spiral, 472; ileocolic, 472
Valves: of heart, 85, 353, 478, 480; of shell, 380, 382; of veins, 86
Variations, 609; kinds of, 621; causes of, 626
Vascular system, see Blood-vessels, Arteries, Veins
Vas deferens, see Spermiduct, Wolffian duct
Vasa efferentia, see efferent ducts
Veins: *Frog*, 17, 78; *Fish*, 421; *Rabbit*, 483; embryo Vertebrate, 568
Velum: of Medusa, 281
Velum palati, 465
Vena cava, see Veins
Vent, see Anus
Ventral, 7
Ventricle, see Heart
Ventricles of brain, 139, 141, 488, 490, 558
Vermiform appendix, 472
Vertebra and vertebral column, 14, 30, 31, 416, 450, 556, 573
Vertebrarterial canal, see Canal
Vertebrata, 197; general characters of, 411
Vessels, see Blood-vessels
Vestibule, see Urinogenital canal
Vestige, vestigial, 141, 480, 589
Vibrissæ, 440
Villi: of intestine, 72, 472; of chorion, 581
Viscera, abdominal, 18, 434, 470
Visceral arches and clefts, 415, 418; and see Branchial apertures
Visceral ganglion, 392
Visceral layer of peritoneum, 25, 300, 548
Visceral skeleton, 418
Vitamins, 69
Vitelline membrane, 533
Vitelline vessels, 568
Vitreous chamber and humour, 165
Vocal cords, 128, 474
Vocal sacs, 8
Volvox: occurrence and movement, 218; structure, 219; reproduction, 219
Vomer, see Skull
Vomerine teeth, 15
Vomero-nasal organ, 494
Vorticella: occurrence and general characters, 236; structure, 236; reproduction, 241; conjugation, 242; means of dispersal, 243; encystation, 242; spore-formation, 243; metamorphosis, 243
Vulva, 440, 504

W

Walking-leaf insect, 615
Walruses, 511
Wasp, 379
Waste-products, 9, 62, 225
Water-flea, 371
Whales, 511
Wheel-animalcules, 402
Whelk, 395
White matter of brain and spinal cord, 138, 142, 151
Wolf, 515
Wolffian body, see Epididymis
,, duct, 571
Wombats, 508
Wood-louse, 371
Work and waste, 62, 132, 208
Worms, 323
Wrist, see Carpus

X

Xiphisternum, 46, 455

Y

Yellow cells of Earthworm, 299, 302
Yolk, yolk-granules or spheres, 175, 533, 543; and see under various types
Yolk-cells, 180, 181
Yolk-plug, 180, 549
Yolk-sac, 550, 554

Z

Zona radiata, 554
Zoochlorella, 269
Zoœa, 344
Zooid, 242, and see Macrozooid and Microzooid
Zoology, 1
Zoomastigina, 221
Zoophytes, see Hydroid polypes
Zygapophysis, 31, 451
Zygoma, zygomatic arch, 448, 449
Zygote, 177, 242, 253

GOVT. GIRLS COLLEGE
SRINAGAR
ACC. NO. 592
LIBRARY

12 4-63

PRINTED IN GREAT BRITAIN BY
RICHARD CLAY AND COMPANY LTD.
BUNGAY, SUFFOLK.

ME. 6. 63

63

GOVT GIRLS COLLEGE
SIALKOT
ACC NO 592
LIBRARY